UNIVERSIDADE DE LISBOA

FACULDADE DE MEDICINA VETERINÁRIA

ANALYSIS OF POULTRY TRADE NETWORKS TO IMPROVE RISK-BASED SURVEILLANCE: A SURVEY STUDY IN GUJARAT, INDIA

SARA ALEXANDRA CORREIA SEQUEIRA

ORIENTADOR(A):
Professor Doutor Dirk Udo Pfeiffer
COORIENTADOR(A):
Doutora Yolanda Maria Vaz
TUTOR(A):
Mestre Telmo Renato Landeiro Raposo Pina Nunes

2022

UNIVERSIDADE DE LISBOA

FACULDADE DE MEDICINA VETERINÁRIA

ANALYSIS OF POULTRY TRADE NETWORKS TO IMPROVE RISK-BASED SURVEILLANCE: A SURVEY STUDY IN GUJARAT, INDIA

SARA ALEXANDRA CORREIA SEQUEIRA

DISSERTAÇÃO DE MESTRADO INTEGRADO EM MEDICINA VETERINÁRIA

JÚRI

PRESIDENTE:

Doutor João Bettencourt Barcelos Cota

VOGAIS:

Doutora Ana Rita Barroso Cunha de Sá Henriques

Professor Doutor Dirk Udo Pfeiffer

ORIENTADOR:

Professor Doutor Dirk Udo Pfeiffer

COORIENTADORA:

Doutora Yolanda Maria Vaz

TUTOR:

Mestre Telmo Renato Landeiro Raposo Pina Nunes

2022

DECLARAÇÃO RELATIVA ÀS CONDIÇÕES DE REPRODUÇÃO DA DISSERTAÇÃO

Nome: Sara Alexandra Correia Sequeira

Título da Tese ou Dissertação: ANALYSIS OF POULTRY TRADE NETWORKS TO IMPROVE RISK-BASED SURVEILLANCE: A SURVEY STUDY IN GUJARAT, INDIA

Ano de conclusão (indicar o da data da realização das provas públicas): 2022

Designação do curso de Mestrado ou de Doutoramento: Mestrado Integrado em Medicina Veterinária

Área científica em que melhor se enquadra (assinale uma):

☐ Clínica ☐ Produção Animal e Segurança Alimentar

☐ Morfologia e Função ☒ Sanidade Animal

Declaro sobre compromisso de honra que a tese ou dissertação agora entregue corresponde à que foi aprovada pelo júri constituído pela Faculdade de Medicina Veterinária da ULISBOA.

Declaro que concedo à Faculdade de Medicina Veterinária e aos seus agentes uma licença não-exclusiva para arquivar e tornar acessível, nomeadamente através do seu repositório institucional, nas condições abaixo indicadas, a minha tese ou dissertação, no todo ou em parte, em suporte digital.

Declaro que autorizo a Faculdade de Medicina Veterinária a arquivar mais de uma cópia da tese ou dissertação e a, sem alterar o seu conteúdo, converter o documento entregue, para qualquer formato de ficheiro, meio ou suporte, para efeitos de preservação e acesso.

Retenho todos os direitos de autor relativos à tese ou dissertação, e o direito de a usar em trabalhos futuros (como artigos ou livros).

Concordo que a minha tese ou dissertação seja colocada no repositório da Faculdade de Medicina Veterinária com o seguinte estatuto (assinale um):

1. ☒ Disponibilização imediata do conjunto do trabalho para acesso mundial;
2. ☐ Disponibilização do conjunto do trabalho para acesso exclusivo na Faculdade de Medicina Veterinária durante o período de ☐ 6 meses, ☐ 12 meses, sendo que após o tempo assinalado autorizo o acesso mundial*;

* Indique o motivo do embargo (OBRIGATÓRIO)

Nos exemplares das dissertações de mestrado ou teses de doutoramento entregues para a prestação de provas na Universidade e dos quais é obrigatoriamente enviado um exemplar para depósito na Biblioteca da Faculdade de Medicina Veterinária da Universidade de Lisboa deve constar uma das seguintes declarações (incluir apenas uma das três):

1. É AUTORIZADA A REPRODUÇÃO INTEGRAL DESTA TESE/TRABALHO APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.
2. É AUTORIZADA A REPRODUÇÃO PARCIAL DESTA TESE/TRABALHO (indicar, caso tal seja necessário, nº máximo de páginas, ilustrações, gráficos, etc.) APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.
3. DE ACORDO COM A LEGISLAÇÃO EM VIGOR, (indicar, caso tal seja necessário, nº máximo de páginas, ilustrações, gráficos, etc.) NÃO É PERMITIDA A REPRODUÇÃO DE QUALQUER PARTE DESTA TESE/TRABALHO.

Faculdade de Medicina Veterinária da Universidade de Lisboa, 17 de Maio de 2022

Assinatura: Sara Sequeira

“Power comes not from knowledge kept but from knowledge shared.”

-Bill Gates

Acknowledgment

Firstly, I would like to express my sincere gratitude to my mentor Professor Telmo Nunes for introducing me to the world of Epidemiology, that ended up being the start of the best adventure of my life. Thank you for your outstanding dedication and work, for sharing so many of your thoughts and time with us and for always believing in my abilities. I hope I can have the privilege to work with you in the future.

My greatest thanks to Professor Dirk Udo Pfeiffer for giving me the opportunity to do research at the highest level and providing invaluable guidance. Thank you for making it possible for me to come to Hong Kong and have the best personal and first professional experience of my life, even though facing a pandemic. I am extremely grateful for having had the possibility of learning directly from a brilliant epidemiologist whose vision, dynamism, sincerity, and motivation have inspired me to pursue this career in the first place.

I would also like to thank to my exceptional team at City University of Hong Kong. A special acknowledgment to Dr. Anne Conan for her consistent guidance and supervision, for sharing her enormous knowledge and for trusting me with several projects that allowed me to develop so many useful skills and to meet a variety of talented people. To my work colleagues Dr. Youngjung Kim, Dr. Tu Tu Win, Dr. Aaron Yang, Dr. Lisa Kohnle and Dr. Joyce Ip for welcoming me with such joy and having contributed to the success of my journey and project.

To Dr. Yolanda Vaz for co-supervising my internship, for all the kindness and for providing helpful contributions when writing this dissertation.

To my friends Laura Jesus, Teresa Coutinho, Daniela Lopes, Miguel Maximino, Sara Rocha, Xavier Canavilhas and Carolina Brandão for their permanent support over six years and for making my ten exam seasons more acceptable and enjoyable. Thank you for making me smile at unexpected times and for the unforgettable moments experienced together.

To my best friend Margarida Antunes, who always knows how to comfort in the hardest moments of anxiety, even when thousands of miles away.

To Nefelie for being my family and best mate during the last 8 months.

Finally, I am the most grateful to my beloved parents and brother without whom I would never be where I am. Thank you for having always supported my professional ambitions and encouraged me to take on work challenges and travelling overseas, even though it seemed like a crazy idea.

Funding

This study was funded by the UKRI GCRF One Health Poultry Hub (Grant No. B/S011269/1), one of twelve interdisciplinary research hubs funded under the UK government's Grand Challenge Research Fund Interdisciplinary Research Hub initiative. The funders were not involved in the conduct of the research or preparation of this paper.

ANALYSIS OF POULTRY TRADE NETWORKS TO IMPROVE RISK-BASED SURVEILLANCE: A SURVEY STUDY IN GUJARAT, INDIA

Abstract

Poultry production and trading in India have been facing a spectacular growth as the demand for poultry products increases. Live bird shops (LBSs) and poultry trading practices are known risk factors in the spread of diseases within poultry production and distribution networks. Although such shops are ubiquitous in India, poultry trading practices and potential impact on disease risk are poorly understood. The objectives of this study were to characterise LBSs for Exotic Broiler (EB) and Desi species, based on trading practices likely to increase infectious risk, and to assess the connectivity between shops through the trade of live poultry.

A questionnaire-based cross-sectional study was conducted in 86 LBSs, selected through a multi-stage sampling method. Eight cities were first purposively selected and, within each city, shops were identified using random spatial sampling. The standardised questionnaires focused on shop management characteristics, hygiene practices and details of their chicken suppliers. The suppliers were then contacted and asked about their trading practices and suppliers until catchment areas were identified. Finally, disease transmission pathways were investigated and poultry trading networks were constructed for EB chickens, to assess the connectivity between shops.

Preliminary descriptive analysis suggests a high heterogeneity in the scale of operations, with daily sales ranging from 6 up to 800 and from 0 to 30 chickens, respectively for EB and Desi species. Most of the shops reported to have unsold chickens at the end of the day, with a proportion of unsold chickens reaching up to 26% and 45.2%, respectively for EB and Desi chickens. Several practices were identified as having a potential influence on disease introduction and transmission, into and within the shops. The transport of chickens from farms to shops typically involves one (85.3%) or two intermediaries (10.3%). While each city obtained chickens only from one to four districts (out of the 33 districts of Gujarat), four districts supplied more than one city.

The described practices may promote pathogen amplification within Gujarat's shops. Moreover, the network shaped by poultry movements, regarding EB chickens, connect distant poultry populations that include both tribal and non-tribal areas, increasing the risk of pathogen spread in the region. Nevertheless, most of the surveyed cities get their supplies from the closest district(s). Further investigation on risk pathways for disease transmission and identification of their geographical and socio-economic determinants are some of the next steps.

Keywords: Chickens, Disease risk, Farming Intensification, Network analysis, Production and distribution network

ANÁLISE DE REDES DE COMÉRCIO DE AVES PARA MELHORAR A VIGILÂNCIA DE RISCO: UM ESTUDO DE CASO EM GUJARAT, INDIA

Resumo

A produção e comércio de aves na Índia tem crescido face ao aumento da procura de produtos avícolas. Os mercados de aves vivas (MAVs) e práticas relacionadas são reconhecidos como fatores de risco na disseminação de doenças entre redes de produção e de distribuição (RPD) de aves. Embora os MAVs sejam ubiquitários na Índia, o impacto das suas práticas na introdução de agente patogénicos são pouco compreendidos. Este estudo tem como objetivo caracterizar os MAVs para as espécies "frango exótico" ("FE") e "Desi", com base nas diferentes práticas de comercialização que podem influenciar o risco de doença, e determinar o grau de conectividade entre mercados através do tráfego de aves vivas.

Um estudo transversal foi conduzido em 86 MAVs, selecionados por método de amostragem multi-etapas. Inicialmente foram selecionadas 8 cidades e, em cada cidade, escolhidos os MAVs por método de amostragem espacial aleatória. Os questionários abordaram características comerciais, práticas de higiene e informação detalhada sobre fornecedores. Os fornecedores foram também contatados e as duas práticas foram novamente investigadas até identificar o local de origem das aves. Foram também investigadas vias de transmissão de agentes patogénicos, de acordo com as práticas descritas, e foram construídas RPD de aves, para avaliar a conectividade entre MAVs.

A análise preliminar sugere uma grande heterogeneidade na escala de operações dos MAVs, com vendas diárias de 6 a 800 e de 0 a 30 galinhas, respetivamente para "FE" e "galinhas Desi". A maioria dos MAVs reportaram ter aves por vender no final de cada dia, com proporções que chegam aos 26% para "FE" e 45.2% para "Desi". Várias práticas foram identificadas como potenciais vias de introdução ou transmissão de doença, para e entre MAVs. O transporte de aves desde áreas de produção até aos estabelecimentos de venda, envolve geralmente 1 (85.3%) ou 2 (10.3%) intermediários. Cada cidade recebe galinhas desde 1 a 4 distritos (num universo de 33 distritos em Gujarat) e 4 distritos fornecem mais do que 1 cidade.

As práticas descritas podem promover a persistência e amplificação de doença em MAVs em Gujarat. A rede formada pelos movimentos de aves entre estabelecimentos interliga populações distantes, incluindo áreas tribais e não tribais, o que incrementa o risco de disseminação de doenças. A maioria das cidades estudadas obtém as suas aves dos distritos vizinhos. Alguns dos próximos passos incluem investigações adicionais de vias da transmissão de doença e identificação de determinantes geográficos e socioeconómicos.

Palavras-chave: Galinhas, Risco de doença, Intensificação agropecuária, Análise de redes, Redes de Produção e Distribuição

Table of contents

List of figures

List of tables

List of abbreviations

AMR – Antimicrobial Resistance

ASF – African Swine Fever

COVID-19 – Coronavirus Disease 2019

EB – Exotic Broiler

FAO – Food and Agriculture Organization

FCR – Food Conversation Ratio

FMV-UL – Faculty of Veterinary Medicine at the University of Lisbon

GCRF – Global Challenges Research Fund

GDP – Gross Domestic Product

GIS – Geographic Information Systems

HPAI – Highly Pathogenic Avian Influenza

HSADL – Indian High Security Animal Disease Laboratory

IBDV – Infectious Bursal Disease Virus

IQR – Interquartile Range

LBS – Live Bird Shop

LPAI – Low Pathogenic Avian Influenza

MVA- Multivariate Analysis

OHPH – One Health Poultry Hub

OHRP – Centre for Applied One Health Research and Policy Advice

OIE – World Organisation for Animal Health

PDN – Production and Distribution Network

SD – Standard Deviation

SDG – Sustainable Development Goals

SISS – New Swine Health Information System

UKRI – United Kingdom Research and Innovation

VCA – Value Chain Analysis

WHO – World Health Organization

List of symbols

% - percentage

= - equal to

> - superior to

< - inferior to

I. Introduction

1. Internship report

From September 7th to December 18th of 2020, a 15-week internship was undertaken in the Faculty of Veterinary Medicine at the University of Lisbon (FMV-UL). Competences regarding the use of R programming (Management System: RStudio), Microsoft Office Excel™ and Structured Query Language (Management System: MySQL) were developed by carrying out several data analysis tasks, under Professor Telmo Nunes supervision.

The activities included statistical data analysis, data management and visualization, in the context of veterinary epidemiology. These tasks were applied to the following projects:

- Describing COVID19 epidemiological situation in Portugal.
- Predicting COVID19's basic and effective reproductive numbers for Portugal and other countries.
- Evaluating the effectiveness of Aujesky's elimination plan, implemented in pig farming in Portugal, with access to the new "Swine Sanitary Information System (SISS)".

Participating in these studies provided the student with important epidemiological skills, such as designing and implementing epidemiological studies, analysing databases and interpreting its results. Other skills acquired included problem-solving and decision-making, enhancing the capacity of the student to recognize the nature of a problem, analyse the ideas and use logic to determine the strengths and weaknesses of the data. In order to frequently discuss the project's progress, weekly meetings were organized with the tutor and the results were presented and compared for each project between university colleagues. This constant collaboration and teamwork also contributed to the improvement of communication and critical-thinking skills, that would be extremely important for a future career in epidemiology.

The curricular internship predominantly took place in the Centre for Applied One Health Research and Policy Advice (OHRP) at City University of Hong Kong from January 7th to August 31st of 2021, supervised by Professor Dirk Udo Pfeiffer. During the first 3 weeks, the work was carried out remotely in a quarantine hotel room, due to COVID19 travel restrictions, while the rest of the internship took place at the university's offices.

During this period, the student participated in two research projects including the *One Health Poultry Hub* and the *Health and Demographic Surveillance System in Livestock* in South Africa. Additionally, the student joined diverse meetings related to other teams' research projects, such as the *African Swine Fever Cross Border Risk Assessment in Southeast Asia* in collaboration with the World Organisation for Animal Health (OIE). Topics related to the specific projects were discussed during weekly meetings with the OHRP team and through collaboration one contributed ideas for the teaching programme at City University of Hong Kong. During the meetings, presentations of relevant projects were made to share knowledge and keep everyone updated on different areas.

Additional courses were virtually attended by the student, namely “Introduction to Veterinary Epidemiology” for Harbin Veterinary Research Institute's College of Veterinary Medicine of China and also the “Virtual Regional Training on Value Chain Analysis for Animal Disease Risk Management” taught by the Food and Agriculture Organization (FAO) of the United Nations (Regional Office for Asia and Pacific). These courses have contributed a lot for the improvement of general concepts on veterinary epidemiology, including quantifying disease risks and rates, understanding the importance of using measures of effect in epidemiological research, interpreting diagnostic tests and how to deal with bias and uncertainty. Basic concepts of value chain analysis (VCA) were developed and its application to animal disease risk management using a participatory approach for data collection. The student has also learnt how economic tools can be used to support VCA.

Moreover, several case studies with relevance to analysis of mathematical epidemiology were presented and discussed on a Research Center Book Club every two weeks, in order to explore various mathematical and statistical concepts.

The average time spent working was 8 hours a day. The total internship time was 8 months (about 35 weeks), totalling about 1400 hours.

2. Project introduction

Poultry production has expanded globally over the past years driven primarily by population growth and urbanisation. The global demand for poultry products explains the faster growth of the sector in consumption and trade comparing with other major agricultural areas.

Poultry has a major role to play in low and middle income countries. Poultry products are cheaper than other livestock options, widely available and it is also seen as a healthy option, being known not only as a source of high-quality protein but also important vitamins and minerals. A chicken can easily provide a meal for the average family without the need of storage facilities, while meat from other livestock (such as pigs or cattle) is kept mainly for special occasions, and there are no major religious limitations in its consumption. Furthermore, commercial poultry industry creates employment opportunities for many people (FAO 2013).

In South and Southeast Asia there has been a rapid intensification and diversification of poultry production, largely driven by specialization, concentration, greater biological efficiency, economies of scale and vertical integration (FAO 2008a) to provide a competitive source of low-priced animal protein to consumers. That has favoured large-scale units rather than small-scale producers. Consequently, poultry industry and the associated feed industry have developed quickly, concentrating themselves close to input sources or final markets and leading to a vertical integration. However, rapid intensification of the poultry industry may be responsible for the introduction of several public health risks. These can include the emergence of foodborne infectious diseases, diseases with epidemic (such as avian influenza)

or even pandemic potential, and an increased antimicrobial resistance (AMR) due to indiscriminate use of antimicrobials.

The global demand for poultry products combined with the necessity of guaranteeing food security and safety, while meeting sustainability patterns, explains the significance of the One Health Poultry Hub (OHPH) (One Health Poultry Hub… 2019). This interdisciplinary research programme aims to identify high-risk behaviours, processes and environments through production networks to address how and why intensification of poultry production increases the risk of animal and human disease outbreaks and AMR. Thus, the project contributes knowledge that will inform policymakers and lead to animal and public health interventions that ensure a safer and quality improved poultry production. At the same time, it brings economic and wellbeing benefits to poultry farmers and suppliers and tends to improve the overall industry performance. The OHPH embraces a One Health approach, recognizing the interconnectedness between animal health, human health and the environment. This way, it directly addresses the Sustainable Development Goals (SDG) of the United Nations (United Nations 2018), in particular: SDG 1 (End poverty in all its forms everywhere), SDG 2 (End hunger, achieve security and improved nutrition, and promote sustainable agriculture), SDG 3 (Ensure healthy lives and promote well-being for all at all ages); and also contributes to: SDG 5 (Achieve gender equality and empower all women and girls), SDG 6 (Ensure availability and sustainable management of water and sanitation for all), SDG 9 (Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation), SDG 11 (Make cities and human settlements inclusive, safe, resilient and sustainable) and, finally, SDG 12 (Ensure sustainable consumption and production patterns);

The Hub has been funded by the Global Challenges Research Fund (GCRF) of the United Kingdom Research and Innovation (UKRI) for 5 years from March 2019.

The programme is implemented in four different countries experiencing rapid growth of their poultry sectors, including Bangladesh, Vietnam, Sri Lanka and India (2 sites), and comprises 27 partners in Asia, Australia and Europe. Each of these four mentioned countries is characterised by different types of poultry production and each of them is facing its own challenges in order to achieve a safer and more sustainable production. Despite that, they are all becoming densely populated and most of its poultry and poultry products are traded through live bird markets or shops, often sold unprocessed. This brings them significant public and poultry health concerns. The OHPH aims to play an important role to overcome these challenges, exploring how intensification of poultry production increases risk of infectious disease and why certain social, economic, cultural, and regulatory contexts can promote certain risky processes and behaviours.

The poultry sector in India employs more than 6 million people, with both small and medium farmers mostly engaged in a contract farming system under larger integrators. Urbanisation and population growth, as well as new food habits, high levels of income and a

rising demand for Indian poultry produce in the export market have been key drivers for poultry industry growth. In India, the Hub programme works in Gujarat and Tamil Nadu states.

Poultry production in Bangladesh has until recently been part of subsistence farming. Commercial farms are growing at a rate of 15% a year and the sector is expected to double in the next decade. However, small-scale backyard farms, where poultry and public health risks are very high, still produce about 70% of the country's poultry population. Moreover, the country still has one of the highest proportions of impoverished livestock keepers in the world, which makes it an essential source of income and sometimes the only protein source.

Similarly, in Vietnam around 70% of the total chicken population are kept in households ranging from a few birds up to 2,000 birds. The number of farms with larger production units, however, is growing fast. The emergence of African Swine Fever (ASF) at the beginning of 2019 is expected to bring major consequences for the poultry industry as consumers switched from pork to other meat sources, such as chickens. Vietnam has hard challenges to face as most animal holdings are small, with poor biosecurity, and illegal poultry trade is known to be made with China over a long border.

Finally, Sri Lanka's poultry industry's expansion in recent years have not been accompanied by matching efficiency and product quality, bringing big concerns when it comes to public health and the country's export ambitions. In this country, poultry accounts for 50% of the livestock gross domestic product (GDP) and it is the most developed livestock industry in the country, making them self-sufficient in poultry meat and eggs. Backyard and free-range production in low income communities of the country, where low biosecurity and poor disease protection measures represent a threat to commercial poultry farming systems, often need support from government programmes.

The OHPH is a large multi-disciplinary project with 21 work packages articulating around mainly four pillars: (1) People, poultry and production, (2) Host-Pathogen interaction dynamics, (3) Flexible funds and (4) Translation to impact. Thus, it provides the benefit of capacity-building, through an interdisciplinary approach that also takes social science into consideration. To provide a strong framework for sampling (WP7), the site team carries out a link tracing study.

In the study analysis here presented under the OHPH, the student will focus on data management and analysis of the data collected by conducting the link tracing study between December of 2019 and March of 2020 in Gujarat, India.

II. Literature Review

1. Location and population in India

The Republic of India, commonly mentioned as India, is considered the world's 7th largest country with an area above 3 million square kilometres (around 1,158,306 square miles) and occupying the greater part of South Asia. Lying entirely on the northern hemisphere, the main land extends between latitudes 8°4'N and 37°6'N and longitudes 68°7'E and 97°25'E. India is surrounded by the Bay of Bengal on the south-east; the Arabian sea on the south-west; the Indian ocean on the south; and it shares borders with a variety of countries such as Pakistan to the west; Bhutan, China and Nepal to the north; and Myanmar and Bangladesh to the east (CIET 2019). Moreover, India shares a maritime border with Sri Lanka, the Maldives, Thailand, Myanmar and Indonesia by its Andaman and Nicobar islands (Figure 1).

Figure 1. Location of India.

India is divided into 28 states, 8 union territories and 742 districts. Its capital is New Delhi (Haryana state) and the most populous city is Mumbai (Maharashtra state). According to the most recent statistics (ORGI 2011a), India is the second most populous country with an estimated population density of about 464/km² and roughly one-sixth of the world's total population (1.39 billion), immediately after China (ORGI 2011c; United Nations 2019).

Indian society is one of the oldest in the world and characterized as multi-ethnic, multi-lingual and multi-religious. Diversity is seen not only in the patterns of rural but also urban settlements (Husain 2014). The proportion of female in the indian population has been growing during the last years, although there were still 52% of men over 48% of women in 2020 (United Nations 2019). Only about 33% of the country's population lives in urban or peri-urban areas while the remaining population lives in rural areas (ICAR-DPR 2008).

The variation in climate in India is strong due to the large size of the country, ranging from tropical in the south to temperate and alpine in the Himalayan north. The temperatures vary from about 10°C during the winter to about 32°C during the summer. There is also a large spatial and temporal variability in the amounts of rainfall over the country (Attri and Tyagi 2013).

1.1. Gujarat

The state of Gujarat has a total surface area of 196 000 square meters (around 6% of the country's area) and with a population of more than 60 million people (around 5% of the population in India). It is the 10th most populated state of the country, with an estimated population density of about 308//km² and located in the western coast of India (see Figure 2), at latitude 23.217ºN and longitude 72.683ºE. It represented the country's fifth highest per capita income for the year 2010-2011 (Chinnasamy et al. 2013) and it is one of the most urbanized states in India, with 44.7% of urban population in 2011 (ORGI 2011a).

Overall, Gujarat has 33 districts subdivided into 226 blocks, 18,618 villages, and 242 towns (Mavalankar et al. 2009; IFPRI 2019). South Gujarat comprises more than 80 percent of the population. Ahmedabad is the largest city of Gujarat with 7.2 million people, of which 84% live in urban areas. Surat and Vadodara, with 6 and 4.2 million people respectively, are other two major cities with a high number of people located in urban cities. Rajkot is the fourth largest city of Gujarat with 3.8 million people in total, with the majority also living in urban areas.

Figure 2. Map of Gujarat state, districts, and respective headquarters (OHPH 2020).

Gujarat includes tribal and non tribal cities and is divided in 8 agroclimatic zones (Figure 3), which varies from one another in terms of habitat, flora, climate, soil and rainfall. India's tribal belt refers to contiguous areas of settlement of tribal population of India. Out of a total of 252 talukas in Gujarat, 26 fall under the tribal belt and about 14.75% of the total population of the state belong to one of the Scheduled Tribes (STs), according to the 2011 Census of India (ORGI 2011b). STs, or tribal community, are officially designated groups of people and among

the most disadvantaged socio-economic groups in India, especially comprised by rural communities (Bharti 2016). While South Gujarat is merely a tribal area (area of settlement of tribal people of India), Middle and North Gujarat areas include both tribal and non tribal cities. On the other hand, North West zone, South and North Saurashtra are classified as non tribal areas. Most tribal talukas (9 out of 26) are located in Surat (OHPH 2020).

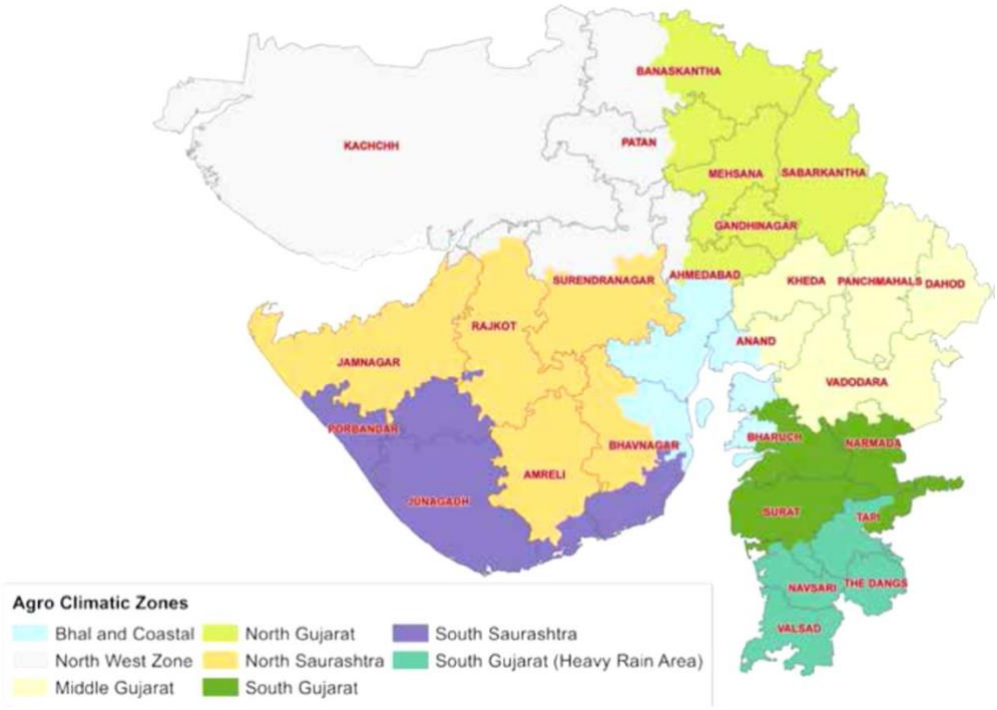

Figure 3: Representation of the different agroclimatic zones of Gujarat, India (adapted from OHPH 2020).

The average temperatures in Gujarat range from 25ºC in January to about 30ºC in July (Husain 2014). Gujarat receives approximately 840 mm yr-1 of precipitation, most of which falls during the months of June through September, and nearly 82% of the state's irrigated land is irrigated with groundwater. A total of 27% of the area of Gujarat is drought prone, which is defined as an area recording less than 60 cm of rainfall annually and in which the variability of rainfall is more than 20 per cent (Chinnasamy et al. 2013).

According to 2011 census, Hinduism is the dominant religion in Gujarat including of about 88.6% of the population.

2. Poultry production in India

The world's poultry meat production expanded to 134 million tonnes in 2019 and was estimated to reach 137 million tonnes in 2020, with an increase of 2.4% over the previous year according to the FAO (FAO 2020a; FAO 2020b). This growth is expected to continue for the next years. Statistics indicate that Asia produces an estimate of 38.15% of the world poultry

meat, whereas the other major produce include North America (18.32%), South America (17.80%), Europe (16.11%) and Africa (4.58%). Similarly, among the various countries, China occupies the first position to the world poultry production (17.63%), followed by the United States of America (17.19%), Brazil (11.89%), Mexico (2.61%) and India (2.30%) (FAO 2020b).

Livestock rearing is one of the most important economic activities in the rural areas of India, providing considerable income to household dependent on agriculture. Many landless labourers derive more than 50 per cent of their income from livestock, especially poultry. Poultry is one of fastest growing segments of the agricultural sector in India, requiring a small capital investment and providing good additional income and job opportunities to the rural population (Husain 2014). During the past few decades India has undergone a major shift, as the poultry industry has transformed itself from the age-old backyard activity into a dynamic industry with larger production units and number of integrated players. The rapid expansion of poultry production has been associated with not only an increase in the scale of production units but also its quality and sophistication through technological advancements (ICAR-DPR 2008).

India has, currently, a self-reliant technology-driven poultry industry, capable to produce all the essential inputs for successful poultry farming and a highly organised large commercial sector accounts for about 80% of total market share, mostly occupying urban or peri-urban locations (Vetrivel and Chandrakumarmangalam 2013). The remaining 20% includes the unorganised or small-scale backyard production that continues to play a key role in supplementary income generation and family nutrition for the poorest, mainly in rural areas.

Nowadays, India represents the fifth largest poultry meat producer. However, in the context of poultry, India is not a major player in global trade, either as an exporter or importer. According to the most recent census (DAHDF 2019), the total number of poultry in the country was 851.81 million in 2019, increased by 16.8% over the previous census (DAHDF 2012). The total backyard poultry reached 317.07 million in the same year, increased by 45.8% over the previous census and the total commercial poultry was 534.74 million in 2019, 4.5% more than the last census. Out of the total poultry population, 812.20 million (95.35%) are concentrated in rural areas and 39.61 million (4.65%) in urban areas, which represented an increase of about 26,5% in the urban areas since 2012. The commercial sector development was more significant in urban areas (17.95% increase) than in rural areas (only 3.95%) (DAHDF 2019).

Broilers are the major source of poultry meat in the country and represent 40% of the poultry population (Biotechnology Research Center 2012). There have been major changes in the structure and size of broiler farms during the last decades and production practices have also modernized. A typical broiler farm used to rear only a few hundred broilers per cycle whereas nowadays it has increased to 10 to 20 thousand birds for a weekly cycle. The usual body weight achieved at 8 weeks of age some decades ago is now realized in 35 to 40 days of age and the food conversation ratio (FCR) has improved from 2.5 to less than 2.0 (DAHDF

2018). Private sector contract farming systems and the vertical integration of broiler enterprises have played a major role in this spectacular growth, especially in southern and western India (where Gujarat is included), contributing to a decline on poultry consumer prices by lowering production and marketing costs. On the opposite side, only 10% of the total broilers in north and eastern region are produced through contract farming (FAO 2008b).

2.1. Poultry production systems in India

FAO classified poultry production systems into four categories (sectors 1 to 4), based on the volume of operation and level of biosecurity: Village or backyard production (sector 4), commercial production with low biosecurity (sector 3) or high biosecurity (sector 2) and, lastly, industrial and integrated production (sector 1) (FAO 2008b; Conan et al. 2012).

The production in the backyard sector (4) is generally based on native breeds, producing both eggs and birds for meat, with a low biosecurity level. The commercial poultry production sector with low biosecurity levels (3) still retains some characteristics of the backyard systems, particularly in selling live birds through wet markets or directly to retail shops. Production units are generally intermediate in scale between backyard systems of up to 200 birds and commercial systems of 10.000 to 50.000 birds. On the opposite, the commercial sector with high biosecurity levels (2) generally comprises of large scaled commercial flocks of 50.000 to 100.000 birds, that can include broilers, layers and breeding birds. Finally, industrial and integrated production sector (1) is the largest and most industrialized sector (more than 10.000 birds) with a vertical integration of the various production stages into a single company, with higher biosecurity levels (Chatterjee and Rajkumar 2015; FAO 2020b).

Table 1. Summary of the poultry population identified in India. Adapted from the 20th Livestock Census (DAHDF 2019).

	Backyard farm	Commercial farm	Total
Total chicken			
Desi	227,595,994	64,847,434	292,443,428
Improved	53,215,221	462,231,485	515,446,706
Total	280,811,215	527,083,122	807,894,337
Ducks	32,503,039	1,008,101	33,511,140
Turkeys	423,374	24,997	448,371
Quails	1,932,310	4,886,382	6,818,692
Others	1,403,419	1,733,972	3,137,391
TOTAL	**317,073,357**	**534,736,574**	**851,809,931**

In India, 65.2% of the poultry population are commercial farms (sector 1 to 3) and 34.8% are backyard farms (sector 4). Chicken dominates the market, comprising nearly 94.8% of the

total poultry population (Table 1). A faster increase took place in the population of improved chickens, also known as Exotic Broilers, compared to native birds, designated as “Desi”. The greater part of the chickens in the country (63.8%) are improved while native chickens are mainly reared in backyard farms, with general low biosecurity levels. The remaining poultry population includes ducks (4.0%), quails (0.8%), turkeys (0.05%) and other birds (0.3%). Other species are reared only in small numbers in areas with specific market demands (Chatterjee and Rajkumar 2015; DAHDF 2019).

2.1.1. Gujarat

Currently, native chickens in both rural and urban areas of Gujarat only constitute of about 21.7% of the country’s chicken population whereas improved chickens already reach 78.3% of the population. Out of the total poultry farms in Gujarat, 87.3% are broiler farms.

As we can see in Table 2, both native and improved chickens are raised mainly in rural areas, either for commercial or backyard farms. Other species reared in minority include ducks (0.04%), turkeys and quails (0.02% each) and other birds (0.06%), also mostly reared in rural communities (Chatterjee and Rajkumar 2015; DAHDF 2019).

Table 2. Summary of the poultry population identified in Gujarat state. Adapted from the 20th Livestock Census (DAHDF 2019).

	Backyard farm			Commercial farm			Total
	Rural	Urban	**Total**	Rural	Urban	**Total**	
Total chicken							
Desi	3,689,346	88,819	3,778,165	862,115	85,764	947,879	4,726,044
Improved	395,477	18,495	413,972	16,086,240	513,411	16,599,651	17,013,623
Total	4,084,823	107,314	4,192,137	16,948,355	599,175	17,547,530	21,739,667
Ducks	8,058	850	8,908	55	0	55	8,963
Turkeys	5,108	54	5,162	0	8	8	5,170
Quails	4,357	738	5,095	12	8	20	5,115
Others	6,316	2,228	8,544	930	5,003	5,933	14,477
TOTAL	4,108,662	111,184	4,411,983	16,949,352	604,194	17,553,546	21,773,392

3. Overview of constraints to poultry production in lower-middle income countries

Various schemes have been initiated to increase the availability of genetically improved poultry, control of diseases, encouraging the farmers to opt for genetically improved species and assure protection against loss of such animals through an established mechanism (DAHDF 2019). Despite the numerous positive changes and growth in the country’s industry, there are still several constraints impacting the productive parameters to be considered.

The spectre of widespread food insecurity has become a global issue in India with the human population reaching 1.39 billion in 2020. There is still a gap between availability and requirement for poultry meat, according to the recommended dietary allowances of the Indian Council of Medical Research (ICMR). However, the need to increase poultry production is occurring at a time when the availability of the main resources is scarce. Many of the feed ingredients may not be available to the poultry industry at the required quantity due to their enhanced export value and increased demand for human food industry. Thus, it is necessary to find strategies to sustain growth of the poultry sector, by increasing the productivity of raw feed ingredients, searching for newer feed resources and by effectively regulating the supplies to feed industry (ICAR-DPR 2008).

At the same time, intensification of production is responsible for problems of waste disposal and soil, air and water pollution (Chatterjee and Rajkumar 2015). Minimising and turning waste products into useable resources could be a good strategy for the efficient use of natural resources. Composting processes of poultry by-products is increasingly common, acting by inactivating harmful pathogens and transforming poultry litter into a fertilizer (Robyn 2012). Other alternatives include the use of poultry waste for production of biogas and electricity (ICAR-DPR 2008; Jahnabi and Buragohain 2018).

Profiles of adaptability in both indigenous and exotic breeds should be explored and genes responsible for conferring better tolerance to higher performing but less adaptative lines should be addressed. Although the introduction of improved genetic material is an important step in the growth and development of the commercial sector, new strains are generally less vigorous and less resistant to disease. In this case, greater productive potential cannot be attained without complementary inputs and improved housing, management and veterinary care conditions (ICAR-DPR 2008; Chatterjee and Rajkumar 2015). Since an assured supply system of modern breed chickens to the country's rural areas is not imminent, the existing traditional sector still has a crucial role in the sector (FAO 2008b).

The lack of basic infrastructure, such as storage and transportation, is still one of the major constraints affecting poultry industry's growth in India. Small-scale producers are at a disadvantage in facing high feed and transport costs, limited access to vaccines, veterinary services and shortage of credit. Unlike industrial producers, where a vertical integration creates financial benefits by reducing operational costs at different stages of the production chain, non-integrated poultry system's costs are likely to be higher (Pica-Ciamarra and Otte 2010; Chatterjee and Rajkumar 2015).

It is important to remember that even in some of the large-scale commercial farms the biosecurity levels are still low, birds are not permanently housed, chickens and other poultry species may be kept together and birds are generally sold alive in a range of different markets. In fact, live bird shops are a common practice in India, posing a risk of recirculation of poultry pathogens such as Highly Pathogenic Avian Influenza (HPAI) virus, and a potential source of

exposure for humans from live poultry. An intensification of production is frequently associated to a fast turnover, complex transport and trading networks, live bird markets with poor biosecurity and an inappropriate use of antimicrobials and vaccines. All the factors can result not only in the introduction of food borne diseases in the chain but also lead to host-pathogen evolution and selection of pathogen variants with increased virulence and vaccine or antimicrobial resistance (AMR) (FAO 2008a). Appropriate housing and floor space also play an important role to improve animal welfare (Fournie et al. 2013). Housing systems that are less stressful for poultry should be adopted and both procedures and handling of chickens should be improved to minimise poultry stress levels (ICAR-DPR 2008).

Inadequate surveillance and under-reporting of poultry diseases remains an issue in India and the lack of data makes difficult to estimate their true impact on Indian communities and their contribution to food insecurity (Robyn 2012). The World Health Organization (WHO) has made several recommendations for national response mechanisms, that are currently in various stages of implementation in India. However, for a country with the size and population of India, the emerging infections (defined as infections whose incidence in humans has increased within the recent past or threatens to increase in the future) remain a real and present concern (Dikid et al. 2013).

3.1. Most frequently reported pathogens in poultry production in India

There are several pathogens (virus, bacteria and parasites) that can have a great impact in poultry production systems with consequences on animal and/or human health.

Considering pathogens with particular impact on poultry's health, there are several viruses causing losses in the sector. A significant viral disease in India and highly contagious in poultry is caused by the Infectious bronchitis virus (IBV, sp. *Avian coronavirus*). It causes major problems in the global poultry industry by affecting poultry's respiratory and urogenital tract. Although vaccination in India was being carried by a specific vaccine strain, different IBV variants have emerged, causing nephropathogenic and reproductive problems in vaccinated flocks inclusive. Hence, the current vaccination program is recommended to be reviewed (Patel et al. 2015). Other viruses present in Gujarat include infectious bursal disease (or Gumboro disease) due to the infectious bursal disease virus (IBDV), Marek's disease caused by an *Alphaherpesvirus* known as "Marek's disease virus", fowl pox resulting from an *Avian poxvirus* and also duck plague caused by Anatid alphaherpesvirus 1 (DAHDF 2016).

Bacterial diseases affecting poultry usually imply the use of antibiotics to alleviate severity of disease, which represent not only major damage to the sector's economy but also create a large problem related to AMR. Infectious coryza is the most important bacteria-caused disease in the country to consider. Caused by *Avibacterium paragallinarum*, it results in upper respiratory disease that affects adult commercial chickens and ends up in a reduction on egg

production rates. None of the therapeutics have been found yet to have a bactericidal effect (Rajurkar et al. 2010). Other bacterial disease affecting poultry reported in Gujarat include chronic respiratory disease caused by *Mycoplasma gallisepticum* (DAHDF 2016).

Parasitic diseases are also an important hurdle to the economy in poultry industry's development. Although the impact of parasitic diseases in birds reared under commercial production systems is decreasing with modernization and biosecurity improvement, poultry kept in backyard systems remain more susceptible to parasitic infections. Birds can be infected through consumption of contaminated feed or water, by litter droppings and scavenging habits. Poultry coccidiosis, caused by *Eimeria* spp., is a prevalent parasitic disease all over India and has a significant impact on poultry production, especially for commercial broiler's industry wherein 95.61% of the total economic loss occurs due to the disease. It causes intestinal tissue damage, resulting into diminished FCR, weight loss and high mortality rates in the farms (Bera et al. 2010; Singh et al. 2021).

Other pathogens, while usually having a minor impact on animal health, can have several public health consequences. Two of the most common foodborne zoonotic agents related to poultry and its products consumption include *Campylobacter* spp. and nontyphoidal *Salmonella* spp., which account for more than 90 percent of all reported bacteria-related food poisoning cases worldwide (Silva 2013). The total number of cases in humans reported of *Campylobacter* spp. infections, although believed to be underestimated, was more than thrice the cases caused by nontyphoidal *Salmonella* spp., *Escherichia coli* O157:H7 and *Listeria monocytogenes* altogether. Poultry act as the reservoir of *Campylobacter* spp. and are the main source of infection for humans, predominantly in poultry meat (Sindhi et al. 2020). This organism is a normal inhabitant of the intestinal tract of most of the animals, however, when faulty handled and improperly processed or stored can be present in the meat, indicating contamination of the carcass. An incidence rate of 4.5% was observed for *Campylobacter* infections in Southern India (Rajendran et al. 2012) and 10.28-13.5% from diarrheic cases in children in Northern India (Ghosh et al. 2013). This bacteria was found to be highly prevalent in poultry, human and environment in Junagadh district of Gujarat state (Sindhi et al. 2020). The isolation of *Campylobacter* spp. from several clinical cases in children further proves that preventive measures should be improved to control the infection in food production systems.

The last mentioned but not the least pathogen circulating in Gujarat is avian influenza virus, which greatly impact both animal and human populations. Based on its pathogenicity, most strains are classified as low pathogenic avian influenza viruses (LPAIV), causing only a few signs of disease in infected birds. However, in poultry, some LPAIV can mutate into highly pathogenic strains (HPAIV), which cause not only a contagious and severe illness among poultry but also pose serious zoonotic risks by possible transmission to humans.

The first case of HPAI H5N1 was confirmed in farms of Navapur in Maharastra state in February of 2006. Further outbreaks in Gujarat and a few places in Madhya Pradesh state

occurred. So far, no human cases have been recorded in India. However, the fact that growth in poultry farming under poor sanitary conditions has been contributing to sustain the virus and climate change has changed the path of migratory birds in Gujarat, which are natural reservoirs of the viruses, make difficult to control the circulation of the virus and its potential ability to cross the species barrier (Martin et al. 2011). Although the Indian High Security Animal Disease Laboratory (HSADL) has developed a homologous killed H5N1 vaccine with a good immune response and a protection rate claimed of over 90% in vaccinated birds, vaccination of poultry for HPAI has been forbidden in India to date. Instead, India follows OIE's guidelines, which encourages culling as control measure (IANS 2006; Parashar 2021).

The LPAIV H9N2 subtype has been consistently isolated in several states across India, including Gujarat, leading to high mortality rates and great egg production losses (Belwal 2016).

4. Main principles of a Poultry Production and Distribution Network (PDN) approach

A poultry production and distribution network (PDN) encompass the poultry farms and the value chains of the poultry industry. Analysis that takes the entire chain of productive activities into account have been referred as value chain analysis (VCA). Nevertheless, an important distinction should be made between "chain", which maps the vertical sequence of events leading to the delivery, consumption and maintenance of a particular good, and "network", which maps both vertical and horizontal linkages between economic actors.

Both animal health and food safety issues can take place in multiple parts of what is termed value chain (VC), which is defined as the chain of actors that mediate the flow of products, information and finance from raw material to the final consumer (Rich et al. 2018). Thus, a VC is a set of interrelated activities that a company uses to add value to its final product, creating a competitive advantage. As represented in Figure 4, VCs describe the processes through which livestock and other inputs pass during the production process. At the same time, it describes the places, where each process happens, and the people involved (FAO 2011).

While VCs are mostly related with the processes of production and distribution of poultry and its products, the concept of PDNs explores the social, economic and cultural structures behind these processes. These investigated structures include relations of patronage, indebtedness, loyalty, political connections and gender relations. A poultry PDN recognizes that different VCs are dynamic and often share common economic actors which are reused and reconfigured on an ongoing basis. When two or more VCs share at least one actor, there is a network linkage. Thus, a VC can be also defined as "*a particular, product-*

based thread of activity that, at a given moment in time, runs through a larger constellation of activities and dynamic configurations embodied in a production network" (Sturgeon 2001).

These networks need to be set up in a way that allows for long-term optimization to reach more consumers over time. By providing a fast and efficient PDN, poultry industry obtains a lot of benefits. Not only the costs and challenges associated with time, human resources and required capital are reduced but the reach for products is also increased geographically.

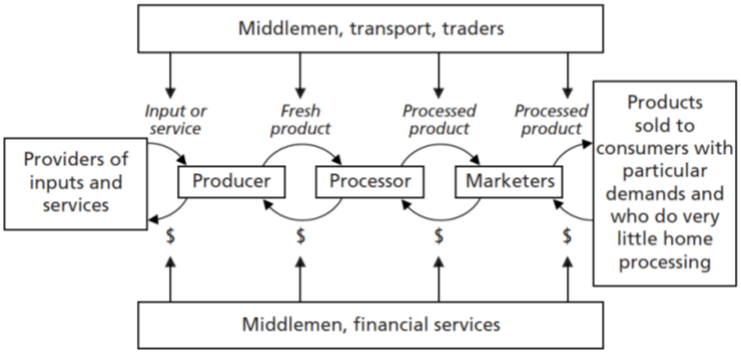

Figure 4. Schematic representation of a livestock value chain (FAO 2011).

5. The importance of risk-based surveillance in disease control: Linking production and distribution networks (PDNs) with epidemiological risk analysis

Surveillance is defined as the "systematic, ongoing collection, collation and analysis of information related to animal health, and the timely dissemination of information to those who need to know, so that action can be taken" (OIE 2019).

A risk-based surveillance can be a more effective approach if there is ready access to information about the population and distribution of risk factors. Instead of conducting a representative selection of animals in the population, this approach uses a selection of animals with higher probability of being infected, or being detected if they are infected, allowing the sensitivity of the surveillance to be increased without necessarily increasing the total number of sampled animals. An understanding of the risk(s) resulting from a specific hazard, respective risk pathway(s) and the factors that determine the risk probability at each step of the risk pathway(s) can be identified by conducting a risk assessment (FAO 2011).

Disease prevention and control should be planned in proportion to the risk of disease. If the hazard in consideration has low relative risk, implementing a highly costly programme can be impracticable and unrealistic. Moreover, disease control efforts often focus on spatial spreading of disease, ignoring the poultry sector's structure and people involved (Rushton et al. 2009). Since strategies which are not supported by producers or traders are likely to fail, the development of risk mitigation policies should always involve the key stakeholders (Robyn

2012; Fournié and Pfeiffer 2013). Therefore, an understanding of the physical and spatial aspects of livestock production systems and how stakeholders operate within the PDNs in question – production and distribution networks (PDNs) analysis - and an evaluation of the epidemiological situation, disease risks and measures applied for its reduction within these production systems – risk analysis (RA) - should always be considered simultaneously.

Despite the challenges encountered over the years, poultry production in India continues to exhibit a spectacular growth. With an increasing demand for chicken meat, the poultry production in India foresees further expansion and industrialization.

Emerging infection diseases in India will continue to challenge public health and threaten to devastate economic development as poultry's population density continues to increase, unless a strategic vision and an effective plan of action are developed to combat these. As animal health directly affects human health, both sectors should work in deep collaboration to increase the transfer of knowledge and avoid slow regulatory processes or communication hindrance. Linking PDN's study with epidemiological risk analysis will help identifying areas where better data are critically needed so that data collection efforts can be focused and prioritised.

III. A large-scale study of two poultry production and distribution networks in Gujarat: implications for disease control and surveillance

Investigations on poultry trading in India and its implications in a One Health perspective are sparse. A few studies have focused on PDNs in other countries enrolled in the OHPH, as in Bangladesh (Moyen et al. 2018; Rebecca and Moyen 2019) and Vietnam (Fournié et al. 2016). However, the scientific literature could not retrieve any study analysing poultry PDNs in India. Therefore, the topology of the live bird shop (LBS) contact network formed by the movements of poultry traders is unknown. Moreover, there is still a lack of understanding by many animal scientists of the living conditions and resource-limitations faced by family poultry producers.

1. Study objectives

The present research project, under the OHPH, aims to develop an understanding of the poultry PDNs in Gujarat while identifying epidemiologically significant nodes, underlying structural factors and resulting practices which may favour or create risk environments for emergence, persistence and/or transmission of poultry and zoonotic diseases. The study followed a number of specific objectives, which can be defined as following:

- Identify and describe LBSs in Gujarat, according to poultry types, with a focus on practices that can create a risk environment for disease emergence and transmission to poultry and human populations;

- Map, for exotic broilers, geographic origins of chickens sold at LBSs in Gujarat cities to understand poultry production dynamics and product flows that can increase the risk of disease dissemination through the production chain;
- Access the connectivity between shops through the trade of live poultry, by comparing their respective supply locations;
- Identify high risk nodes that should be targeted for surveillance and control based on properties of the live poultry trade network.

IV. Material and methods

A cross-sectional study was carried out across the 8 cities through Gujarat state from December 2019 to March 2020. The surveys were conducted in each city to collect data on trading practices of stakeholders from the poultry distribution networks (PDNs). A trained team headed by Dr. Haidaruliman Ismail Paleja (Anand Agricultural University) was responsible for the field investigation in the respective sites.

Two PDNs, commercial Exotic Broiler under integration and Desi backyard farms, were considered to be relevant for the study as they represent a major part of the trade in the region. These two PDNs were studied separately as they are expected to show several differences regarding biosecurity levels and practices within LBSs are likely to be distinct. In both PDNs, live bird retail shops in urban and peri urban areas were thought to have more input and output flow and higher chances of mixing of birds from different locations, age groups and species. Therefore, these sites were defined as the endpoints (targeted population). Endpoints are not necessarily defined as nodes where consumers purchase and/or consume chickens, but the sites where chickens are slaughtered.

A link tracing study (LTS) was conducted to identify the sampling frame for the future biological sampling. The objective of the sampling study is to target farms (50 units) and their linked endpoints (50 units) to compare pathogen population between the farms and the endpoints. The LTS consisted of investigation of endpoints by following a multi-stage sampling method and then of the traders backward in the network using a snowball sampling method. Each endpoint indicated a maximum of three respective chicken suppliers, which could be a farm or a trader, for example. A trader was defined in the study as an individual whose main activity is to buy poultry from other poultry traders or farmers and to sell it, either to another poultry trader or an endpoint. Some live bird shops could be either endpoint, trader or both. The same method was performed with suppliers until the identification of the origin farm.

1. Study area

A multi-stage sampling method was followed to define the study area. To start, eight cities were purposively selected and encompassed an equal proportion of tribal and non-tribal areas.

This selection, based on the Gujarat team's knowledge, included cities that cover the diversity in terms of agroclimatic characteristics, population, food habits and flow of different types of birds, to capture geographical areas differing for factors that can influence risk of transmission. The size of human population and consumption patterns in each city was also taken in consideration.

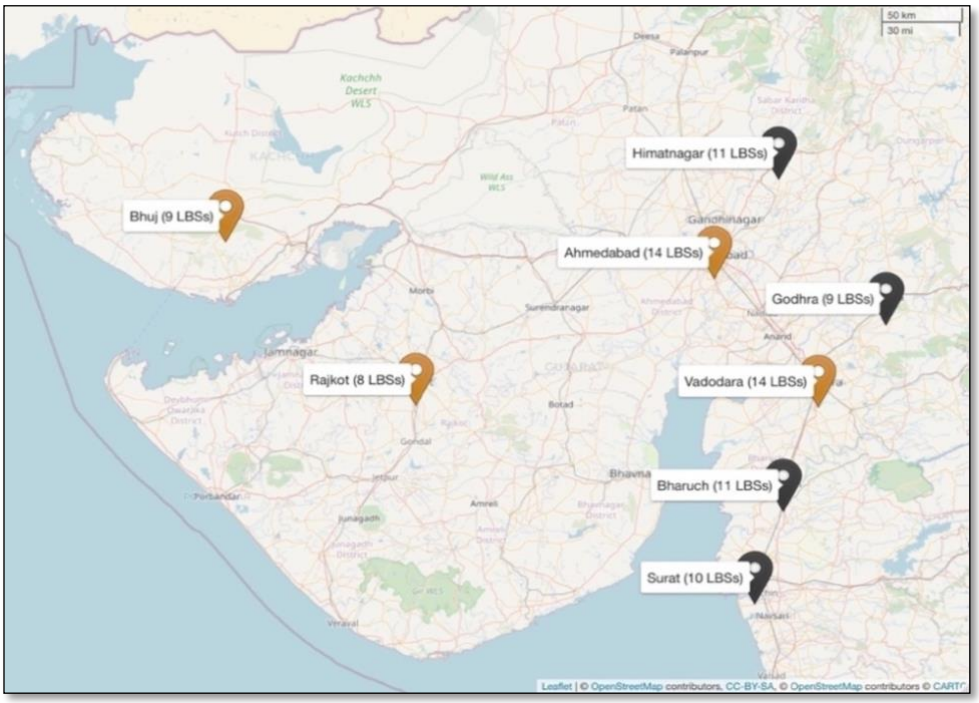

Figure 5. Geographic distribution of the selected tribal (**black icon**), non-tribal (**orange icon**) cities and the respective number of live bird shops (LBSs) interviewed in each city in Gujarat, India.

Table 3. Districts and respective human and poultry populations in the different cities in Gujarat. Adapted from (DAHDF 2019).

Sampled city	District	Human Population	Poultry population
Tribal			
Godhra	Panch Mahals	2,725,485	539,471
Himatnagar	Sabar Kantha	2,428,589	587,152
Bharuch	Bharuch	1,551,019	293,680
Surat	Surat	6,081,322	922,318
Non-tribal			
Bhuj	Kachchh/Kutch	2,092,371	50,004
Rajkot	Rajkot	3,804,558	961,313
Ahmedabad	Ahmadabad	7,214,225	370,332
Vadodara	Vadodara	4,165,626	1,645,689

Four of the major cities represent non-tribal areas, including Bhuj, Rajkot, Ahmedabad and Vadodara. The other four cities correspond to tribal areas, including Godhra, Himatnagar, Bharuch and Surat (Figure 5). The selected cities of Gujarat, respective districts and its human

and poultry population, according to the Indian census of 2011 (Commissioner 2011), are presented in the Table 3.

2. Selection of endpoints

The second phase of the multi-stage sampling method consisted in random spatial sampling, applied to the previously defined cities, in order to select the endpoints. This sampling strategy is especially useful in resource-constrained settings, where there is little time, the research budget is limited and up-to-date and accurate geographic or census data (including maps and household lists) are not available. Spatial sampling methods use geographic information systems (GIS), sample frames containing identifiable geographic units that are randomly selected using a spatial sampling software. This software generates the estimated variables of interest within a minimum number of sampling sites (spatial sampling units) (Kumar 2007; Kondo et al. 2014).

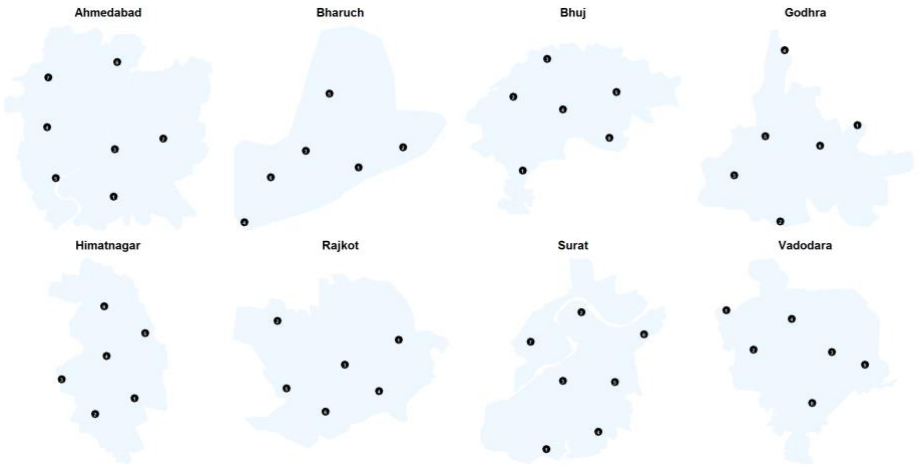

Figure 6. Schematic representation of the sampling locations (black) selected for each city.

Sampling locations were randomly generated within each city's municipal corporation boundaries, while ensuring that the Euclidian distance, between any two geographic units was ≥10% of the distance between the two furthest extremities of the city. In the end, 7 locations were selected in the two largest cities from both tribal and non-tribal areas, respectively Surat and Ahmedabad, and 6 locations in the remaining six cities (Figure 6).

The sample size was defined as 50 for each type of LBS (EB and Desi). For each selected sampling unit, the nearest shops, for each type of chicken, were identified (Figure 7), by asking opportunistically people met in those locations if they knew where the closest shop selling live chickens was located. If the given shop was the nearest to two sampling points, it was allocated to the sampling location with the shortest Euclidian distance, and the second nearest shop was chosen for the other sampling location.

Figure 7. Schematic representation of the sampling locations (black), respective nearest shops and other listed shops (blue) in each city.

If the nearest listed shop only sold one chicken type (e.g., EB), we also identified the closest shop in the vicinity selling the other type (e.g., Desi). After identifying all the necessary endpoints, shop owners or other available individuals in each shop were selected and the interviews were conducted by trained interviewers following the standardized questionnaires for live bird shops (see Chapter 4). Informed oral consent was sought prior to interviewing.

3. Selection of traders

The traders were selected using a snowball sampling method to investigate the origin of the poultry. Thus, based on the interviews of endpoints (Figure 8 – Step 1), the main chicken suppliers (also called traders) were identified for each LBSs (Figure 8 – Step 2) based on the type of chicken sold (maximum 3 suppliers, respectively for each type of chicken supplied). These traders were then contacted and asked about their suppliers (Figure 8 – Step n+2). The same method was repeated until the last supplier level is identified: the farm. It is important to mention that, in some cases, there is more than one trader in the same chain, for example when a given supplier receives birds from another supplier. It is also possible to have a chain with only one level, when a given farm supplies directly to its endpoint.

By using this method, instead of identifying all the intermediaries and farms involved in a given PDN, which would be extremely time-consuming, up to 4 nodes were selected at each level through which a group of chickens have certainly transited. Although the intention was to know the exact origin location of the farm, it was difficult to obtain this information. Therefore, location at the village or district level was obtained. At the end, a list of locations of poultry origins were gathered and defined as the catching areas for each particular LBS.

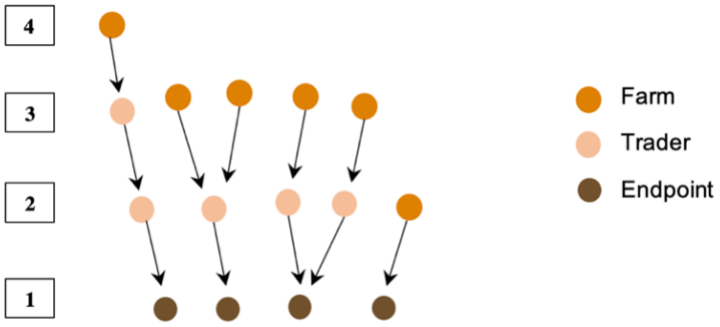

Figure 8. Illustration of the snowball sampling principle. Some shops (endpoints) are selected following the random spatial sampling methodology described (1). In each visited shop, vendors are asked about contact details of the middlemen supplying them (acting as intermediaries between the chicken origin and respective LBS) (2). Finally, a sample of identified intermediaries are interviewed and asked about their own suppliers (3) and the method is carried out until the last supplier level is identified (3 and 4).

4. Questionnaire survey

The link tracing study was carried out through surveys combining of one observation form and one standardized questionnaire for the LBSs, and one standardized questionnaire, for mobile traders. Both questionnaires were developed in English and translated in Gujarati.

The LBS observation form includes 54 questions for the interviewer to fill according to what was observed in each LBS (Annexe 1). This form covers information on location and housing structure characteristics, poultry population structure (poultry types and other species) and husbandry practices (including hygiene, slaughtering and processing information).

The LBS questionnaire was composed of 64 questions focusing on demographic details of farmers, shop management characteristics and trading practices (including animal sales, purchases and surplus), information on herd structure, husbandry practices (including hygiene, slaughtering and processing information) and socio-economical information (Annexe 2)

The questionnaire for mobile traders comprises 27 questions and includes information about sales, purchases and surplus features and also their trading practices (Annexe 3).

5. Data entry and data management

All the collected data was processed and stored using ODK (Open Data Kit) system and each file was then uploaded in a Microsoft Office Excel™ format for data cleaning. The dataset was several times revised in discussion with the field team.

Data cleaning consists in transforming the raw data, which may contain wrong data types (e.g., numbers stored as strings), wrong category labels, unexpected values, characters or even missing data, into consistent data to prevent future disparities in the analysis. This procedure comprises of a substantial part of the analysis, contributing to significantly improve the quality of the data.

6. Statistical analysis

6.1. Conceptual framework for the analysis

The data analysis in this study, represented in Figure 9, consisted in two phases: descriptive statistical and analytic analyses. The first phase of the descriptive statistical analysis included an exploratory and visual investigation of the data frame, by using different types of plots, to make a description of the practices for both LBS and traders' questionnaires. Since different poultry types are associated with different production systems, the descriptive analysis was carried out separately between commercial EB and backyard Desi PDNs.

Analytic analysis consisted of a multivariate analysis (MVA) to identify determinant of trade, diseases risk factors and a social network analysis (SNA). The student's involvement in the project included the preparation of the multivariate analysis by developing risk pathways and the SNA. SNA was carried only for Exotic Broiler's PDN to detect hotspots, which are nodes where disease burden or transmission are likely to be more elevated or efficient.

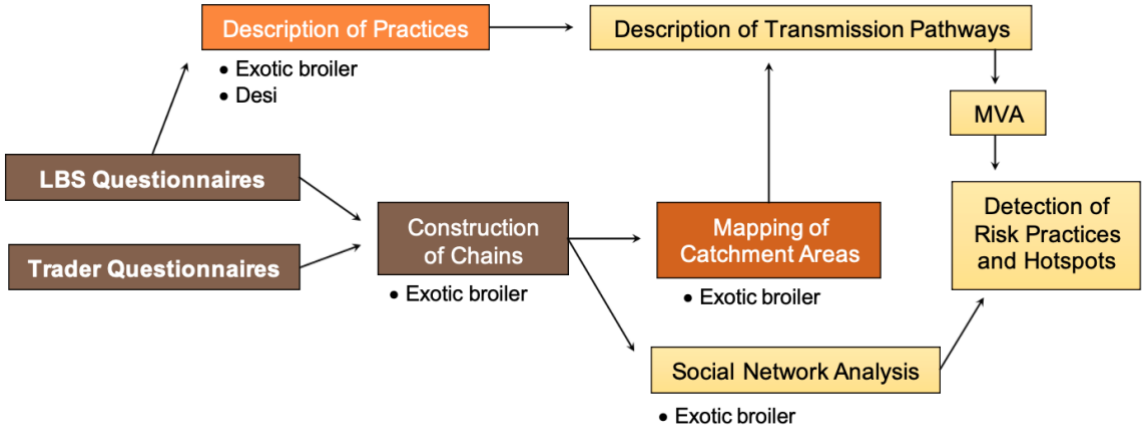

Figure 9. Schematic representation of the conceptual framework for this study analysis, including descriptive (orange) and analytic (yellow) statistical analyses. The first part of the analysis consisted in a description of the practices for both LBS and trader's questionnaires. Both questionnaires were also interpreted and used to construct the chains for EBs. Then, market catchment areas were mapped for exotic chickens and disease transmission pathways were investigated for a future multivariate analysis (MVA). Finally, social networks analysis was performed in order to detect high risk nodes or hotspots.

All analyses were performed using R programming (Management System: RStudio, Vienna, Austria), with access to the following R packages: "dplyr" (Wickham 2021a), "data.table" (Dowle and Srinivasan 2021), "lubridate" (Spinu et al. 2021), "stringr" (Wickham 2019), "ggplot2" (Wickham et al. 2021), "ggpubr" (Kasssambara 2020), "tidyverse" (Wickham 2021b), "maptools" (Bivand and Lewin-Koh 2021), "tmaptools" (Tennekes 2021), "leaflet" (Cheng et al. 2021), "geojsonio" (Scott and Chamberlain 2021), "tibble" (Müller and Wickham 2021), "visNetwork" (Almende et al. 2021), "igraph" (Amestoy et al. 2020) and "sna" (Butts 2020).

6.2. Descriptive statistical analysis

6.2.1. Description of practices

Numerical variables were summarized using averages, standard deviations (SD) and medians with interquartile ranges (IQR), while binary and categorical variables were described as absolute and relative frequencies.

Histograms were used to evaluate frequency distribution, how tightly are frequencies grouped, how symmetrical the data are and if and how it is skewed. To show the relationship between numeric and categorical variables or two numerical variables, bar plots or scatter plots were applied, respectively. Pie charts were used to emphasize relative proportions of the data. Finally, boxplots depict the distributions of multiple groups of numerical data, indicating the range of the central 50% of the data (Interquartile Range – IQR) with a central line marking the median value (Q2/50th percentile). Values numerically distant from the rest of the observations in a boxplot were identified as outliers.

6.2.2. Mapping of catchment areas

Given that EB chickens are not only the main species sold but also the one selected for the sampling study in most of the participating countries of the OHPH, chains were constructed only for this species to start. The chain included endpoints, their intermediaries and respective catchment areas, whose definitions were previously mentioned. For each city, the catching areas, or districts of origin for EB chickens, were mapped for all LBSs of the city by using their district location.

6.3. Analytic statistical analysis

6.3.1. Risk pathways for disease transmission

As a first step for a future multivariate analysis (MVA), risk pathways for disease introduction were investigated. This part of the analysis consisted of looking at the questionnaires and data available and select variables that could show a risk for a pathogen to be transmitted. It was performed to evaluate how specific practices can influence disease introduction into the LBS, then the transmission in the poultry living present in the shop and, finally, the transmission from poultry to humans in the LBS.

Two risk pathway diagrams were constructed to show the possible risk pathways for disease introduction into LBS facilities and the risk pathways of spreading within the LBSs (for poultry and human), respectively. The selected variables were grouped in accordance to the type of assessment conducted: Release or introduction assessment; Animal exposure assessment; and Human exposure assessment.

6.3.2. Social network analysis (SNA)

Social network analysis (SNA) was used for identifying relationships and characterizing and quantifying patterns of interaction among stakeholders in Gujarat.

A weighted and directed partial network was built for EB chickens. The considered network was bipartite, which means nodes were assigned two different partitions. A node was defined as either (i) surveyed LBSs in a given city or (ii) poultry farms in a given district, and the links corresponded to chicken paths, respectively from their district origin to their endpoint city location. Since the network was bipartite and directed, links could only occur between nodes of different partitions and exclusively in one direction (from a district to a city), respectively. Each link could include one or more traders, and the links' weight represented the number of traders involved. Figure 10 gives a representation of a directed network, including both suppliers (S) and endpoints (E) as nodes.

In order to assess the level of network connectivity, the density (proportion of existing links among all possible district-city links in the network) was calculated, considering a directed and bipartite network. The number and sizes of weakly connected components in the network were identified, which correspond to the maximal subsets of nodes in which all nodes are mutually accessible regardless the direction of the links. This measure help evaluate whether nodes in a network can indirectly reach one another.

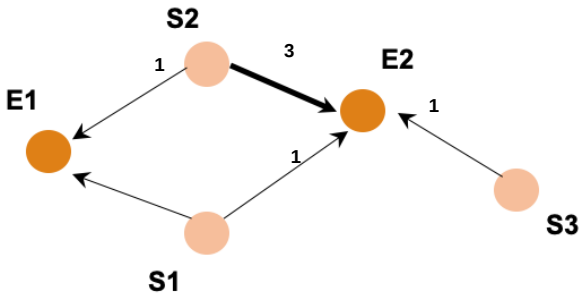

Figure 10. Representation of a network graph and its key elements (nodes and arcs). The observed graph represents a directed and weighted network where nodes (dots) correspond either to endpoints (E) or supplier (LBS) locations, and arcs (links) indicate interactions and flows between the nodes. Arcs were weighted according to the number of interactions (intermediaries) between nodes (bold).

For each node, two types of centrality measures were calculated to rank them and discuss their role in the network: degree and weighted degree (Kurscheid et al. 2017; Newman 2018).

For each node, degree centrality was calculated to measure the number of directed links between nodes (Kurscheid et al. 2017; Newman 2018). In a directed network, the degree value comprises the out-degree and in-degree. For each node i, the out-degree represents the number of nodes receiving supplies from node i while the in-degree is the number of nodes trading poultry towards node i. Since it is a bipartite network, out-degree values correspond to the number of cities supplied by a given district while in-degree values will represent the

number of supplying districts sending poultry to a given city. In Figure 10, for example, S2 has an out-degree of 2 while E2 has an in-degree of 3.

In the studied network, weighted degree (or strength) centrality was also calculated to measure the number of intermediaries within each link. Once again, as a directed network, weighted in-degree (or in-strength) corresponds to the number of intermediaries sending poultry to a given city while weighted out-degree (or out-strength) mirrors the number of intermediaries trading birds from a given district. Looking at Figure 10, as an example, S2 has an out-strength of 4 (3+1) while E2 has an in-strength of 5 (3+1+1).

7. Ethics

The research proposal of this study received ethics approval by the London School of Hygiene & Tropical Medicine, UK (ref. 10214-1). Participation in the questionnaire survey was voluntary, and oral consent was obtained from poultry vendors and traders at all intervening sites. There were no animal samples used in this study.

V. Results

1. Descriptive statistical analysis

1.1. Sociodemographic characteristics

A total of 86 LBS vendors, with ages ranging from 18 to 64 years old, were interviewed with an average age of about 39 years (SD = 11.9). The interviewees were grouped into five age categories: from 15 to 24 years old, between 25 to 34 years old, from 35 to 44 years old, from 45 to 54 years old and from 55 to 64 years old, inclusive. Most of the vendors (n=24, 27.9%) belong to the middle-age group, from 35 to 44 years old, and almost all (n=84, 97.7%) were male, while only 2 were female (2.3%).

A big part of the vendors (n=39, 45.3%) have only achieved lower secondary school, followed by primary (n=13, 15.1%), tertiary education (n=12, 14.0%) and, finally, higher secondary or no education (n=11, 12.8% each), according to the International Standard Classification of Education (UNESCO 2011). Most respondents with no education (10 out of 11; 90.9%) or just primary level of education (9 out of 13; 69.2%) are 35 years old or older, while most of the respondents with tertiary level of education (10 out of 12; 83.3%) are between 25-34 years old. Table 4 summarises all the population characteristics.

Most of the interviewees were shop owners (n=74, 86.0%), followed by shop employees (n=6, 7.0%), owner/manager relatives (n=5, 5.8%) and the employer manager (n=1, 1.2%). Only a few sellers (n=23, 26.7%) work by themselves in the respective live bird shop. Among the remaining 63 sellers (73.3%), 34 (54.0%) have employees working for them, 24 (38.1%) work with relatives and only 5 (7.9%) work with both employees and family members. The surveyed LBSs of this study have a median number of workers of 2 and 50% of the values lie

within 1 to 3 workers (for both observed and answered questionnaires). The highest number of workers observed by the interviewer in a shop was 11.

Table 4. Summary of the demographic features of the study population (including gender, age group, education level and religion).

Gender	N	%
Male	84	97.7%
Female	2	2.3%
Age Group		
15-24	9	10.5%
25-34	23	26.7%
35-44	24	27.9%
45-54	19	22.1%
55-64	11	12.8%
Education level		
None	11	12.8%
Primary	13	15.1%
Lower Secondary	39	45.3%
Higher Secondary	11	12.8%
Tertiary	12	14.0%
Religion		
Muslim	82	95.3%
Hindu	4	4.7%

1.2. Live bird shop characteristics

1.2.1. Housing Structure

Most of the LBSs (n=75, 87.2%) have a permanent structure. Around 7.0% of shops (n=6) have a non-permanent structure and the remaining 5.8% (n=5) do not have a specific structure. From the ones with a non-permanent structure, all sell Desi chicken (3 only and 3 Desi and EBs), 66.7% (n=4) are uncovered shops and the remaining 33.3% (n=2) are covered. In 76,7% of the cases (n=66) where the shop structure is permanent, the building is shared with other shops, residences or offices.

Most of the shops (n=63, 73.3%) have their floor constructed with tiles. When the shop sells EB, with or without Desi, concrete floor (n=11, 15.3%), and earth (n=5, 6.9%) are the second and third most used materials, respectively, while for LBSs selling only Desi, earth (n=5, 35.7%) and concrete floor (n=1, 7.1%) come in second and third, respectively.

Most of the live bird shops (70 LBSs; 81.4%) are located in a high traffic street. Among these, 21 (30.0%) do not have any live bird shop in their vicinity (within 100 meters), 12 (17.1%) have other shops in their vicinity (between 50 to 100 meters of distance), 19 (27.1%) are in close contact with other shops (within less than 50 meters) and 18 (25.7%) have other shops in the direct neighbourhood. Among the remaining shops (n=16, 18.6%), not located in a high traffic street, 6 (37.5%) do not have other shops in their vicinity, 5 (31.3%) are in close contact

with other shops (between 50 to 100 meters of distance) and 5 (31.3%) have LBSs in the direct neighbourhood (Figure 11).

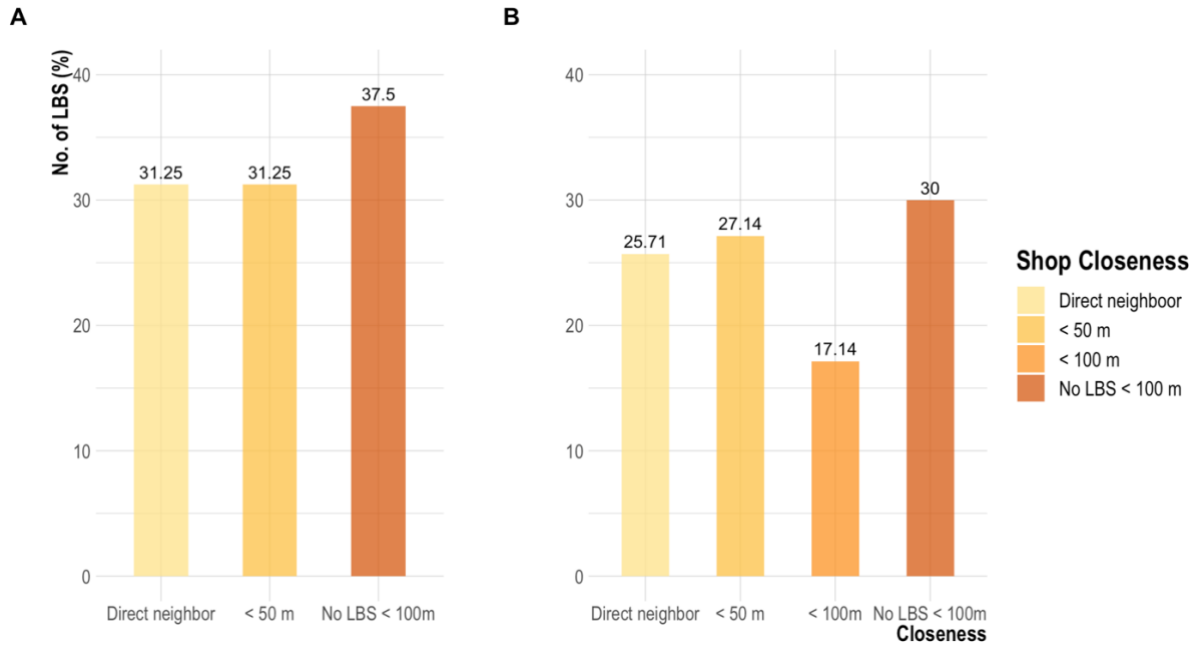

Figure 11. Closeness to other shops and high traffic streets: LBSs are differentiated into shops not close to high traffic streets (A) and the ones that are located in a high traffic street (B) and classified according to their closeness to other shops in their vicinity: direct neighbor, less than 50 meters, less than 100 meters or no LBS in a 100 meters vicinity (values in percentage).

1.2.2. Poultry and other species

The greater part of the selected LBSs sell both types of chicken (n=47, 54.6%), followed by LBSs selling only Exotic Broiler (n=25, 29.1%) and the ones selling only Desi (n=14, 16.3%). Thus, a total of 83.7% of the shops have Exotic Broilers and 70.09% have Desi (Figure 12). The number of interviewed shops by cities as well as the distribution by type of chicken sold between tribal cities and non tribal cities is described in the Table 5.

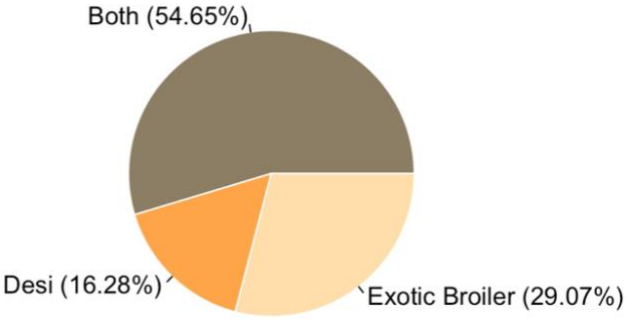

Figure 12. Distribution of chicken types of interest sold in the selected shops.

Independently of the type of chicken sold, 50% of the LBSs (n=43) keep their poultry in front of the shop. If not in front of the shop, poultry is kept in a separate room (n=33, 38.4%)

or inside the shop (n=25, 29.1%). Other locations (n=10, 11.6%) include another floor in the shop, roof area, side of the shop and on the street.

In most part of the cases (n=67, 77.9%), poultry are kept in cages. The cages are usually made of steel/metal for all the shops, although wooden and plastic cages were also seen in some of these shops (n=2, 29% for each of them). Less frequently, poultry were seen in free roaming with legs untied (n=27, 31.4%) and/or with legs tied (n=11, 12,8%). Other options include poultry kept in baskets, in a shelf and in plastic bags (n=1, 1.2%, for each of them).

Table 5. Distribution of shops selling each chicken type in tribal and non tribal cities of Gujarat.

	Both		Exotic Broiler		Desi	
	N	**%**	**N**	**%**	**N**	**%**
Tribal	**20**	**48.8%**	**12**	**29.3%**	**9**	**21.9%**
Godhra	6	66.7%	2	22.2%	1	11.1%
Himatnagar	4	36.4%	4	36.4%	3	27.2%
Bharuch	2	18.2%	5	45.4%	4	36.4%
Surat	8	80.0%	1	10.0%	1	10.0%
Non-tribal	**27**	**60.0%**	**13**	**28.9%**	**5**	**11.1%**
Bhuj	4	44.4%	3	33.3%	2	22.2%
Rajkot	6	75.0%	1	10.0%	1	10.0%
Ahmedabad	10	71.4%	4	28.6%	-	-
Vadodara	7	50.0%	5	35.7%	2	14.3%

Other bird species sold in these shops include quails and pigeons, which are sold in equal proportions (n= 1; 1.2%). Most of the LBSs (n=56, 65.12%) were not seen keeping different poultry species together in their facilities. Among 30 shops keeping different species in the same space, 25 (83.3%) keep them in separated areas/cages, although in 11 of the cases (44.0%) the cages are kept in close contact with each other. Only a small part of the LBSs (n=5, 5.8%) were observed keeping poultry species in direct contact with each other.

Moreover, even though most of the shops do not sell other alive animals than poultry in their facilities, a smaller percentage (n=14, 16.3%) have mentioned to sell goats. One shop selling only Desi chickens, one selling EB and one selling both types, reported to sell buffalos, seafood and sheep, respectively. One shop has also reported that wild birds are sold in its close vicinity (<100 meters).

The various roaming animals observed by the interviewer close to the shop include dogs (n=19, 22.1%) that sometimes are not owned by the respective LBS, cats (n=4, 4.7%), wild birds (n=4, 4.7%) and rodents (n=1, 1.2%). Dogs were seen in close contact with the poultry in 11 LBS (57.9% of the times) and also in the slaughtering area in 1 LBS (5.3%). Cats were seen feeding on waste and in close contact with the poultry in 3 of the shops (75% of them).

1.2.3. Slaughtering and processing

Poultry is mainly slaughtered inside the shop (n=71, 82.6%), regardless the type of chicken sold. When this happens, it is usually close to an open drain (n=59, 83.1%), on the ground (n=11, 15.5%) or less frequently in a bucket (n=1, 1.4%). Although in a smaller percentage (n=10, 14.1%), some shops slaughter their poultry in front of the shop instead. The backyard (n=2, 2.8%) and another room (n=2, 2.8%) were other options referred and one case (1.2%) reported that the birds are slaughtered directly in the supplier.

Around 70.9% of the shops (n=61) sell pre-prepared/dressed chickens, but the greater part of the LBSs do not have a defeathering machine (n=81, 94.2%). Among the ones with the machine (n=5, 5.8%), 80% (n=4) have it located inside the shop while 20% (n=1) have it in the backyard/backroom. Only one of these shops (20%) was observed to boil the birds before defeathering.

Only 26.7% of the LBS (n=23) have the waiting/slaughtering area separated from the selling area. When separated from the selling area, the slaughtering area has most commonly a permanent structure (n= 19, 82.6%), sometimes uncovered (n=3 of 19, 15.8%), while only a small part has a slaughtering area structure that can be dismantled (n=4, 17.4%), mostly uncovered (n= 3 of 4, 75.0%).

1.2.4. Cleaning, disinfection and sanitary conditions

All the shops reported clean and disinfect their space each day of the week. The majority (n=56, 65.1%) clean the LBS three times per day (at opening hours, closure time and night). The remaining shops clean either 2 times (n=15, 17.44%), 1 time (n=14, 16.3%), or less commonly 4 times daily (n=1, 1.2%). Within the shops cleaning 2 times daily, 80% (n=12) do it at opening and closing hours, 13.3% (n=2) at opening hours and night, while only 6.7% (n=1) during closing time and at night. Considering the shops cleaning 1 time per day, 50% (n=7) do it during opening hours, 42.9% (n=6) during closure time and only 7.1% (n=1) at night.

The most common equipment used for cleaning are brushes or other manual tools only, although 2 shops (2.3%) have mentioned to have a pressure cleaner and one shop (1.2%) has also a floor scrubbing machine.

During observation, most shops (n=71, 82.6%) had a small amount of faeces on the floor, appearing to have been cleaned recently. Nevertheless, around 11.6% (n=10) contained a large amount of faeces and feathers on the floor. The floor of the remaining 5.8% of the LBSs (n=5) was earth. Among the shops using cages (72, 83.7%), 80.56% (n=58) were seen with a small amount of faeces in the cages and 19.44% (n=14) with a large amount of faeces and feathers. Figure 13 compares the cleanliness of the floor between shops that keep their poultry in cages and shops that do not use cages at all.

Considering the shops observed having water supply (n=81, 94.2%), the greater part gets their water from a tap in the shop (n=68, 84.0%), followed by buckets (n=6, 7.4%), a tap in the street (n=5, 6.2%) or other sources (n=4, 5.0%).

Within 62 LBSs with drains, 43 (69.4%) looked recently cleaned, 18 (29.0%) were filled with dirty water and waste, and 1 (1.6%) contained blood in the drains. In five of the shops no water supply was observed.

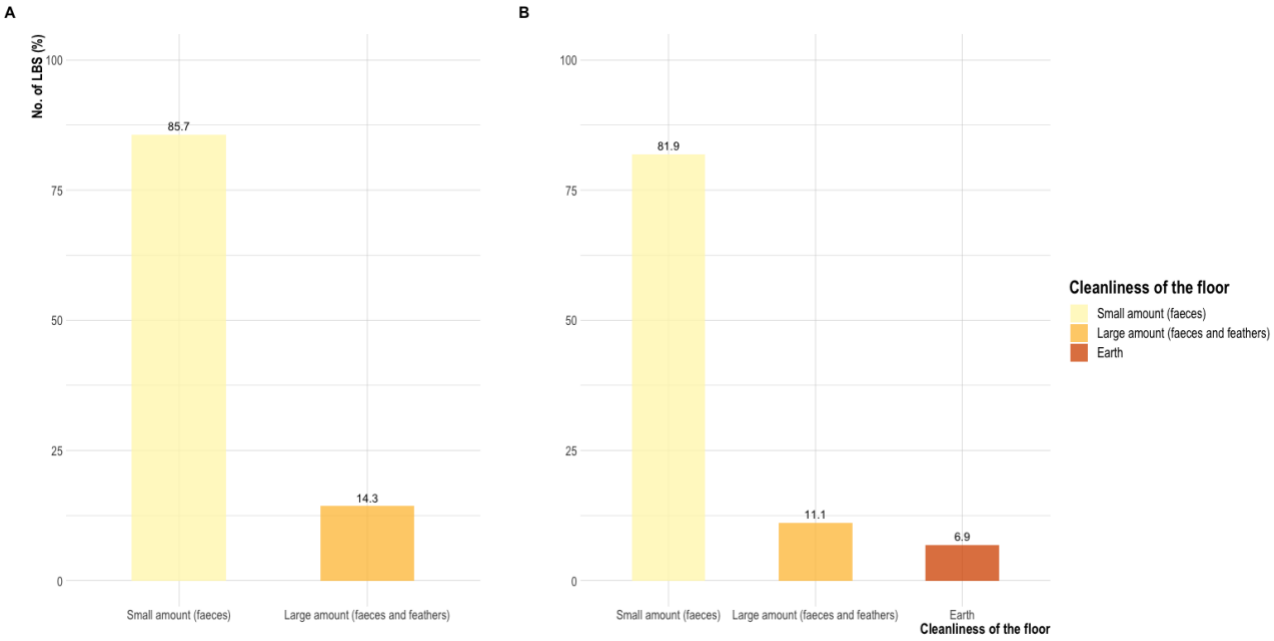

Figure 13. Usage of cages and comparative cleanliness of the floor: LBSs are differentiated into shops that keep their poultry in cages (A) and the ones that do not (B) and classified according to the cleanliness of the floor in the respective shop: a small amount of faeces was observed in the floor (looked recently cleaned), a large amount of faeces and feathers were seen in the shop's floor or the floor was earth.

The biggest percentage of the shops (n=53, 61.6%) clean and disinfect their slaughtering area every hour or at least twice daily (n=27, 31.4%). Three of the shops (3.5%) reported to clean and disinfect the slaughtering area 3 times per day and other three LBSs (3.5%) only once daily. Shops selling both types of chicken reported to clean and disinfect the slaughtering area more frequently during opening hours (n=43, 91.5%) over closure time or at night (n=33, 70.2%, each). The shops selling only EB or Desi clean and disinfect the slaughtering area always during closure time and some of them also during opening hours (n=23, 92.0% and n=12, 85.7%, respectively) or at night (n=17, 68.0% and n=11, 78.6%, respectively).

The only Individual Protection Equipment (IPE) used in the LBSs were closed shoes, aprons and masks. None of the workers were seen using gloves, hair covers, coveralls or any specific protective clothes. Around 69.8% of the LBSs (n=60) did not have workers using closed shoes, while in 10.5% (n=9) and 8.1% (n=7) of the LBSs, all workers were seen using shoes or almost all the workers (>90%), respectively. Only 4.7% (n=4) of the LBSs had all the workers using masks and most of the shops (n=78, 90.7%) did not have workers using masks at all. None of the workers was using aprons in the majority of the shops (n=82, 95.3%).

The waste is collected every day in all the visited LBS. For most of them (n=42, 48.8%), the waste is collected by a municipal corporation and, if not, given or sold for animal feed (n=22, 25.6%). Most shops (n=55, 64.0%) have reported that they do not have the knowledge on how the waste is managed, after collected. One LBS reported to bury the waste and 2 shops reported that sometimes the waste is given to indigenous communities (called Adivashi) for food free of cost. Only one (1.2%) shop reported to have information that the feathers, offal and other solid waste are sold, after collected, to consumers keeping dogs and cats as pets.

A big part of the shops (n=81, 94.2%) throw their waste from slaughtering and processing directly in a bin, regardless of the type of chicken sold. For shops selling both chicken types or only EB, it is also common to leave this waste on the floor (n=14, 16.3%). Some shops pile it up away from poultry (n=10, 11.6%) while others have blood, offal and carcasses next to live poultry (n=8, 9.3%). Less frequently (n=4, 4.7%), the waste from slaughtering and processing is kept in the street until further collection.

1.3. Daily operating hours

The vast majority of the LBSs (n=85, 98.8%) are open every day of the week. Only one of the shops (1.2%), located in Godhra, closes on Sundays. There was no indication of variations in their schedule according to the lunar calendar.

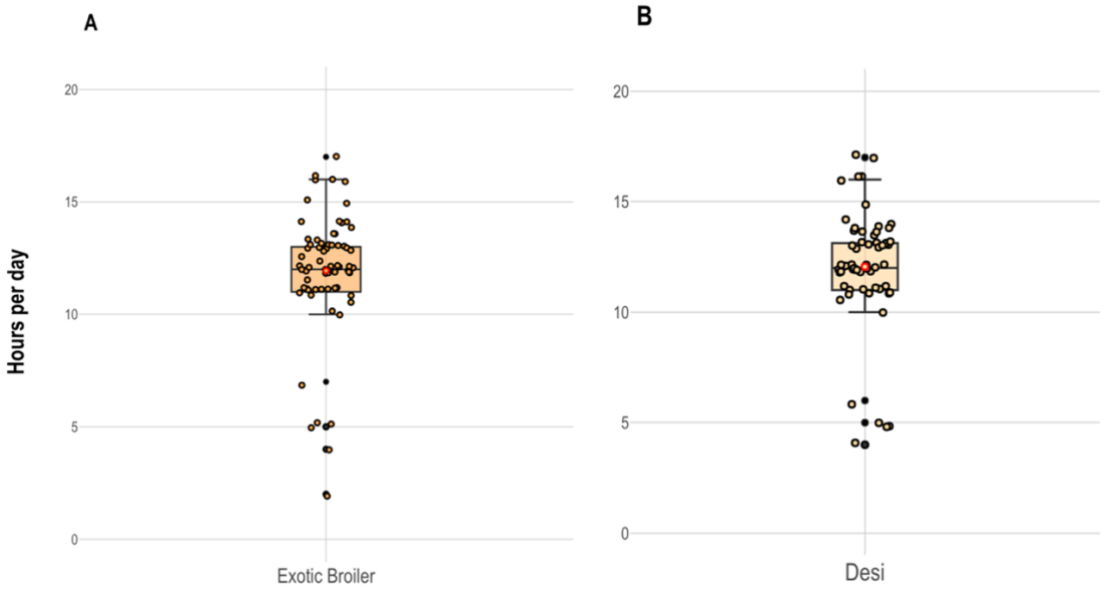

Figure 14. Boxplot representing the length of time (in hours) LBSs are open per day for shops selling Exotic Broiler (A) and for shops selling Desi (B). Includes the values of all observations (black circles) and the median daily operating hours (red circle).

The number of daily operating hours varies between 10 to 17 hours, with an average of 11.9 hours (SD = 2.7) and a median of 12 hours for both types of LBS (Figure 14). Fifty percent of the respondents reported to sell chickens from 11-13 daily hours or from 11-13.1 hours (95% confidence interval), respectively for shops selling EB and shops selling Desi.

The average operating hours for shops also vary according to their city location. Poultry shops located in Godhra and Bhuj cities have the biggest variability in terms of their daily schedule.

1.4. Sales and destination

1.4.1. Overall view

Considering the highest and lowest number of chickens likely to be sold in a day, the daily average number of sales was calculated for each LBS. The total number of sales in a LBS per day varies from just 3 chickens up to 800 chickens, with a median of 26 chickens sold daily. Exotic Boiler is the species sold in higher proportion between the two described.

1.4.1.1. Exotic Broiler sales

The number of chickens sold per day for LBSs selling EB range from 6 up to 800 chickens. The observations follow a bottom skewed distribution (median < mean), with a median number of sales of only 30 chickens but an average daily number of sales of 94 chickens (SD= 167).

The distribution of sales, represented in Figure 15 (A), is quite similar for either shops selling only EB or shops that also sell Desi, although the first have sold more chickens in general. The median number of EB chickens sold in a day was similar for both types of shop (33 chickens sold a day). Nevertheless, EB chickens are more likely to be sold in higher numbers per day (>30 chickens) for shops selling exclusively this breed (Q2-Q3 interval of 67 chickens and 46 chickens, respectively for shops selling only EB and shops also selling Desi).

1.4.1.2. Desi sales

For shops selling Desi chickens, the daily number of sales ranges between 0 and 30 chickens. The observations follow a bottom skewed distribution (median < mean), with a median number of sales of only 4 chickens per day and an average daily number of sales of 6 chickens (SD= 6).

As represented in Figure 15 (B), shops that sell exclusively Desi are more likely to sell more chickens per day in comparison to the ones selling EB as well. Even though some shops selling both chicken types do not sell Desi, that does not mean that they do not practice any sales since EBs are also an option. While fifty percent of the shops selling both types of chicken sell from 0 to 13 chickens a day, shops selling only the indigenous species sell up to 18 chickens.

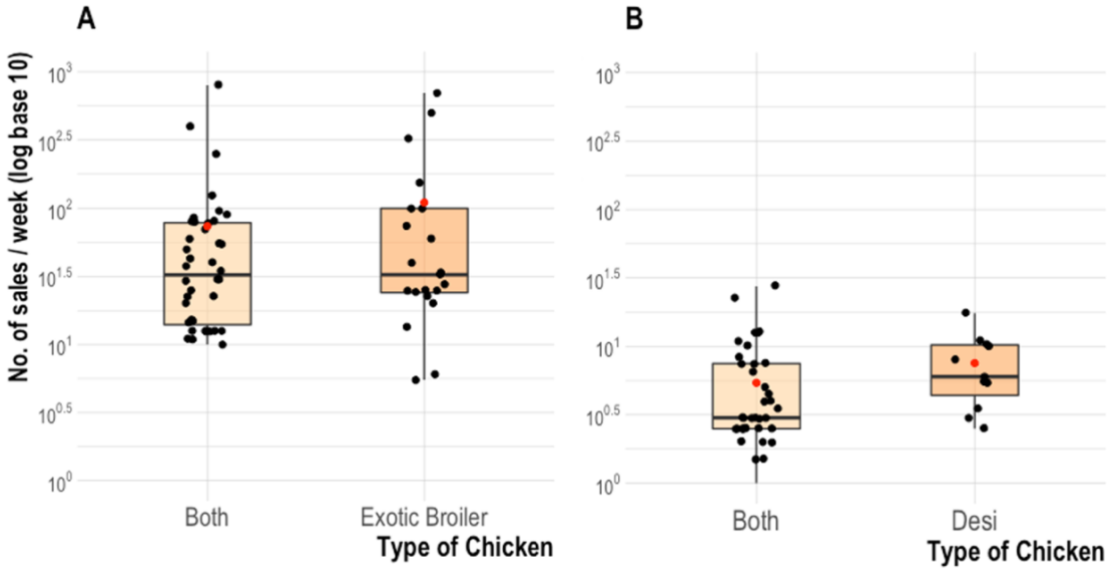

Figure 15. Boxplots representing the distribution of relative daily sales of (A) Exotic Broilers and (B) Desi chickens in each type of LBS (selling both, only EB or only Desi). A log scale of base 10 was applied so that a given visual distance represents a constant proportional change.

1.4.2. Proportion of sales carried to each destination

In general, most of the shops (n=64, 74.4%) sell the biggest proportion of their sales (>90%) directly to consumers (Table 6). Only a small proportion of the shops (n=22, 25.6%) practice sales to restaurants, either in a very small (<10%) or small (10-50%) proportions. A minority of the shops (n=6, 7.0%) carry their sales to other traders (between 2 to 5 other traders). LBSs selling only Desi chickens do not sell to other traders. Finally, only 4 LBSs (4.7%) reported to sell chickens for catering (2 LBS selling both species and 1 LBS of each EB and Desi types).

Table 6. Proportion of sales carried to each destination (Traders, Restaurants, Consumers or Catering).

	Proportion of Sales (%)						
	>90%	**90%**	**50-90%**	**50%**	**10-50%**	**<10%**	**Total**
Destination							
Consumers	74.4%	13.9%	4.7%	4.7%	-	2.3%	100%
Restaurants	-	-	3.5%	-	16.3%	5.8%	25.6%
Traders	-	1.2%	-	-	4.6%	1.2%	7.0%
Catering	-	-	1.2%	-	2.3%	1.2%	4.7%

1.5. Chicken suppliers

1.5.1. Overall view

Live poultry shops can either receive supplies every day of the week or not receive supplies at all. There is a high variability in the distribution of values, either for shops selling EBs and shops selling Desi. A total of 93.0% of the shops reported to get their supplies until 11 a.m. in the morning, with 61.6% receiving birds from 8 a.m. to 10 a.m., just before or during opening time.

1.5.2. Exotic Broiler shops

The average number of days that a certain LBS, selling EB, received EB supplies ranges from 0 and 7 days. The distribution of values for shops selling both species and for shops selling only EB are shown in Figure 16 (A).

In general, shops selling only EB are more likely to receive supplies of EBs more days per week than LBS selling both chicken types.

1.5.3. Desi shops

For Desi chicken shops, the average number of days in a week that a LBS received Desi supplies also varies between 0 and 7 days. Figure 16 (B) shows that the median number of days receiving supplies per week was similar for shops selling Desi only and both. Around 50% of the shops selling only Desi receive their supplies only 2 to 5 days per week.

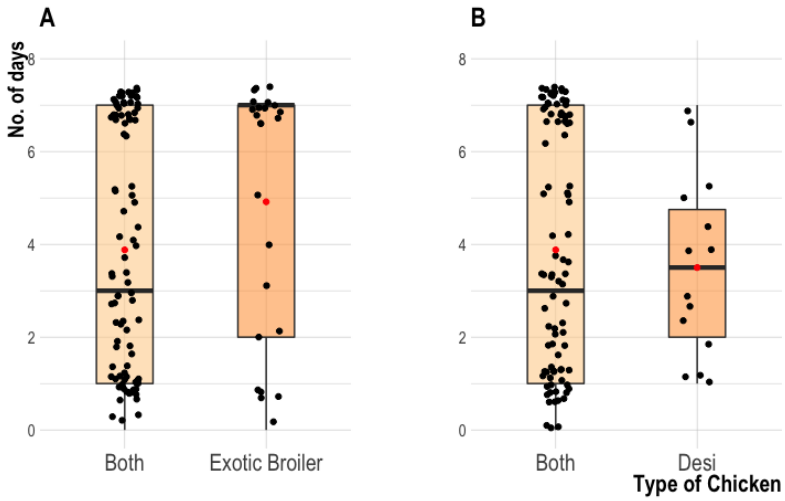

Figure 16. Boxplots representing the distribution of days per week that each LBS received supplies from each supplier category, respectively of (A) Exotic Broilers and (B) Desi chickens.

1.6. Proportion of unsold chickens

1.6.1. Overall view

The average weekly number of days that a certain LBS had unsold birds left in the shop ranges from 0 to 7 days, either for shops selling EB or Desi chickens (Figure 17).

Considering EB sales (Figure 17 - A), there was not a big variation in the number of days having surpluses between shops selling only this chicken type and the ones that also sell Desi (similar median of 5 days per week). On the contrary, a higher variance was observed in the number of unsold EBs (var = 651.4) compared with the number of Desi chickens sold (var = 21.4) in the study population. For shops selling only EB, there was always at least 1 day with chickens left unsold for all the shops.

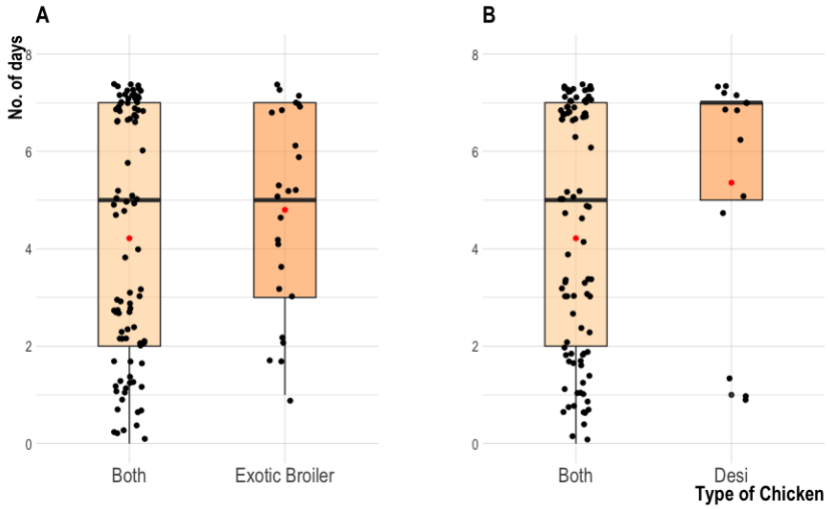

Figure 17. Boxplots representing the distribution of days in a week that each LBS left unsold chickens, respectively of (A) Exotic Broilers and (B) Desi chickens.

For shops selling Desi, it is more likely to have unsold Desi chickens more days per week when selling only this chicken species than for LBSs selling both types of chicken (median of 7 days a week comparing with 5 weekly days, respectively).

Most of the shops (n=78, 90.7%) keep their unsold birds in the shop during the night. The remaining shops, which represent only a small part (n=8, 9.3%), either keep their surpluses at the vendor's place (n=5, 5.8%) or at both shop and vendor's venues (n=3, 3.5%).

1.6.2. Exotic Broiler shops

Leaving unsold EB chickens in a working day is a common occurrence in the study population, even though most of the shops leave less than 30% of their EBs unsold. None of the shops reported to sell all their EB birds at the end of the day. For this species, the daily number of poultry left unsold varies from only 2 up to 175 chickens, with a proportion of unsold chickens varying between 2.4% and 45.2%. Figure 18 describe the number of EBs left unsold in relation to the number of EBs sold.

The median proportion of unsold chickens was lower for shops selling both types of chicken (13%) over shops that only sell EB (17%), although the first tend to exhibit higher values of unsold chickens (Figure 19). One of the shops selling only EB could not report their number of unsold chickens.

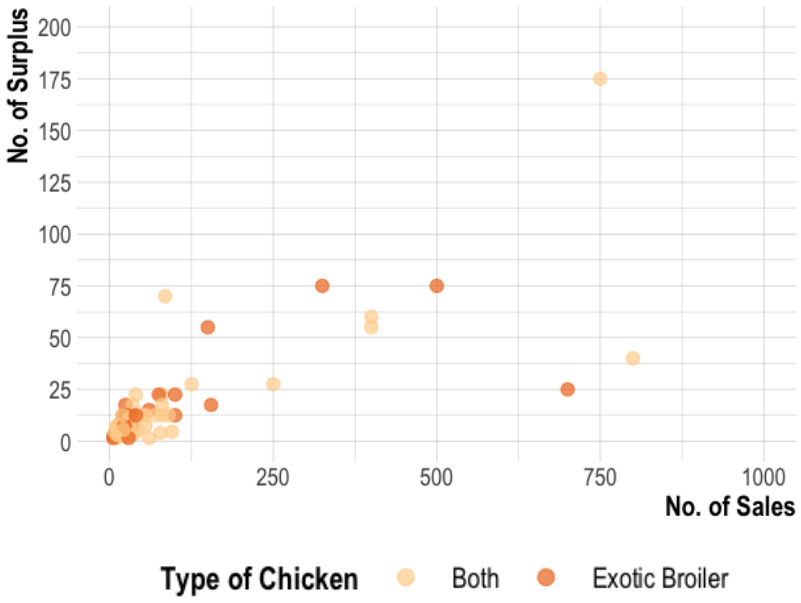

Figure 18. Relation between the number of Exotic Broiler chickens sold and left unsold in a day. The horizontal axis represents the daily number of sales, the vertical axis shows the daily number of surpluses, and the size of the points illustrates the proportion of unsold chickens. The orange dots represent shops selling only EB while the yellow dots correspond to shops selling both types of chicken.

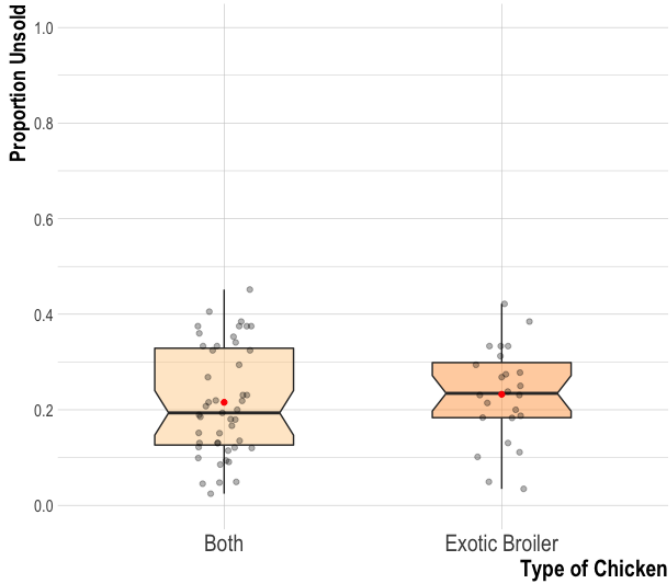

Figure 19. Proportion of unsold EBs in a day and its distribution by type of LBS.

1.6.3. Desi shops

The daily number of poultry left unsold varies from 0 up to 30 chickens, with a proportion of unsold chickens reaching up to 92.3%. Only about 8% of the shops reported to sell all their Desi birds at the end of the day. Figure 20 describe the number of Desi chickens left unsold in relation to their sales.

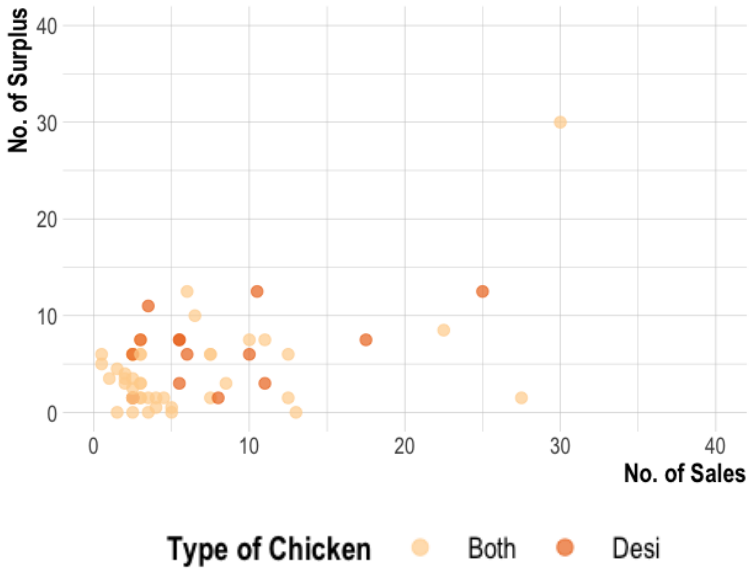

Figure 20. Relation between the number of Desi chickens sold and left unsold in a day. The horizontal axis (x axis) represents the number of sales, the vertical axis (y axis) shows the number of surpluses, and the size of the points illustrates the proportion of unsold chickens. The orange dots represent shops selling only Desi while the yellow dots correspond to shops selling both types of chicken.

While for shops selling both chicken species the proportion of unsold Desi chickens ranges from 0 to 92%, for shops selling only Desi varies just between 3% to 76%. The median proportion of unsold Desi was lower for shops selling both chicken species (37% over 44% for shops selling only Desi). The proportions of unsold Desi chickens have a greater variability for shops selling both chicken types, with 50% of the LBSs revealing proportions ranging from 10 to 64%, comparing with shops selling only Desi, where 50% of the LBS have proportions from 25 to 58%. Two of the shops selling both types of chicken reported to leave more than 90% (90.9% and 92.3%) of their chickens unsold (Figure 21).

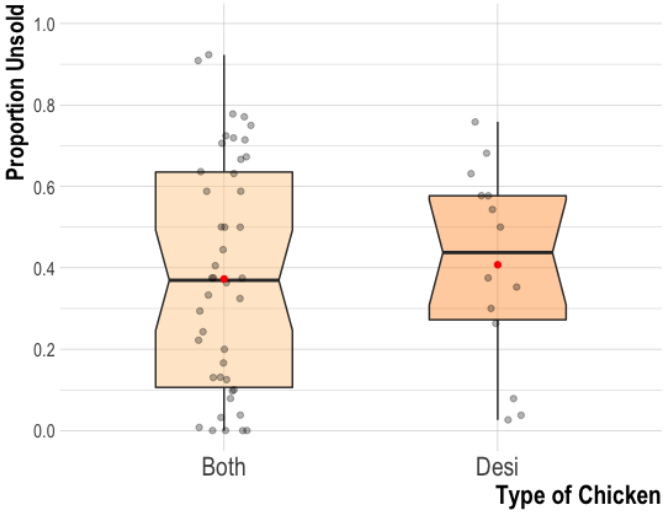

Figure 21. Proportion of unsold Desi chickens in a day and its distribution by type of LBS.

2. Mapping of catchment areas

Catchment areas were mapped for all LBSs by city where they are located (Figure 22). Most of the surveyed cities get chicken supplies from the closest district(s), apart from Ahmedabad and Surat.

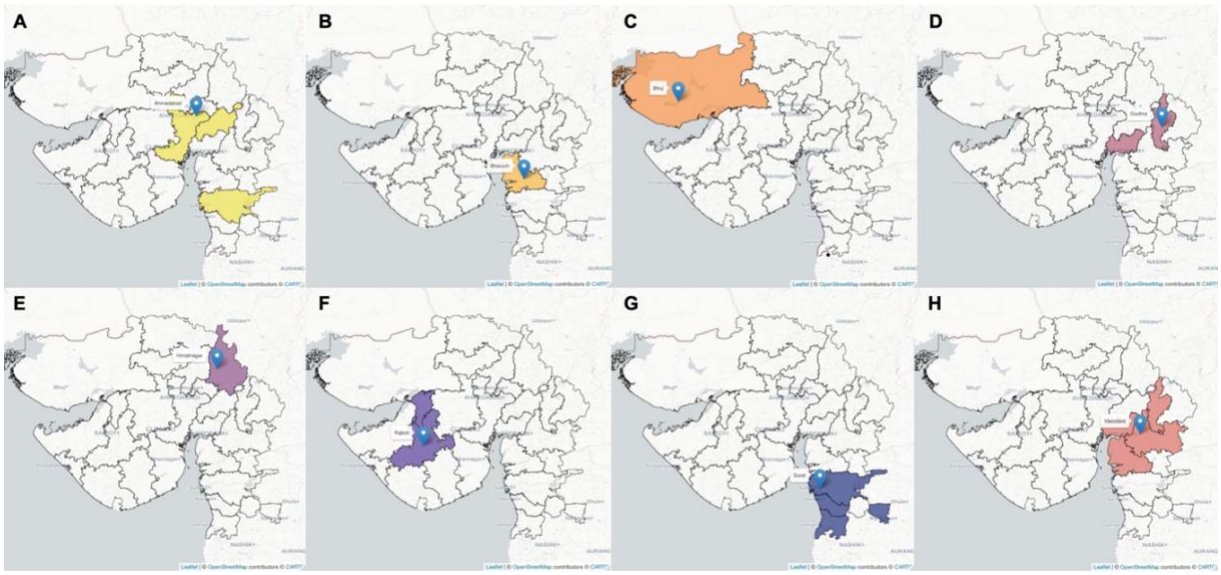

Figure 22. Catchment areas (or districts of origin) identified for the live poultry shops located in each city. Respectively for (A) Ahmedabad, (B) Bharuch, (C) Bhuj, (D) Godhra, (E) Himatnagar, (F) Rajkot, (G) Surat and (H) Vadodara.

Ahmedabad city not only receives supplies from two of the closest districts (respectively Ahmedabad and Kheda) but also from Surat district, located in the southeast of Gujarat (Figure 22 - A). Surat city, on the other hand, is not only supplied by the three southern districts of Gujarat (respectively Surat, Navsari and Valsad) but also from Nashik district, which belongs to Maharashtra state (Figure 22 - G).

The majority of the cities (n= 5, 62.5%) obtain chickens from more than one up to four districts, among the total thirty-three of Gujarat. Vadodara city receives chickens from the largest number of districts, which includes four different regions. Ahmedabad, Rajkot and Surat get supplies from three districts, including their own, and Godhra only gets them from two. Finally, Bharuch, Bhuj and Himatnagar cities receive supplies from one district only, where they are located.

The distribution of catchment areas according to the city supplied, tribal or non tribal, is represented in Figure 23. Both tribal and non tribal cities receive their supplies mainly from the surrounding areas. While tribal cities obtained chickens from a total of eight different districts, non tribal cities get their supplies from ten districts. Three of the tribal cities (Bharuch, Surat and Godhra) share their supply areas with non tribal cities (Ahmedabad and Vadodara).

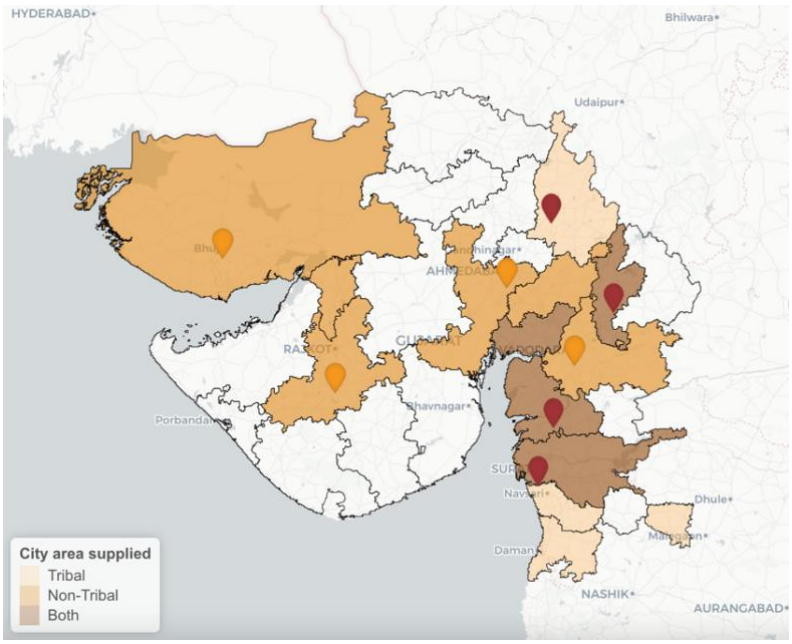

Figure 23. Catchment areas (or districts of origin) identified for the surveyed live poultry shops, respectively supplying tribal and non tribal cities. In the figure, red pins refer to tribal cities while orange pins represent non tribal cities.

While each city obtained chickens from one to four districts, four districts supplied more than one city (Figure 24). Bharuch and Surat districts not only supply its administrative headquarters cities (also named Bharuch and Surat cities) but also Vadodara and Ahmedabad, respectively. Finally, Panch Mahals as well as Anand districts supply both Vadodara and Godhra cities.

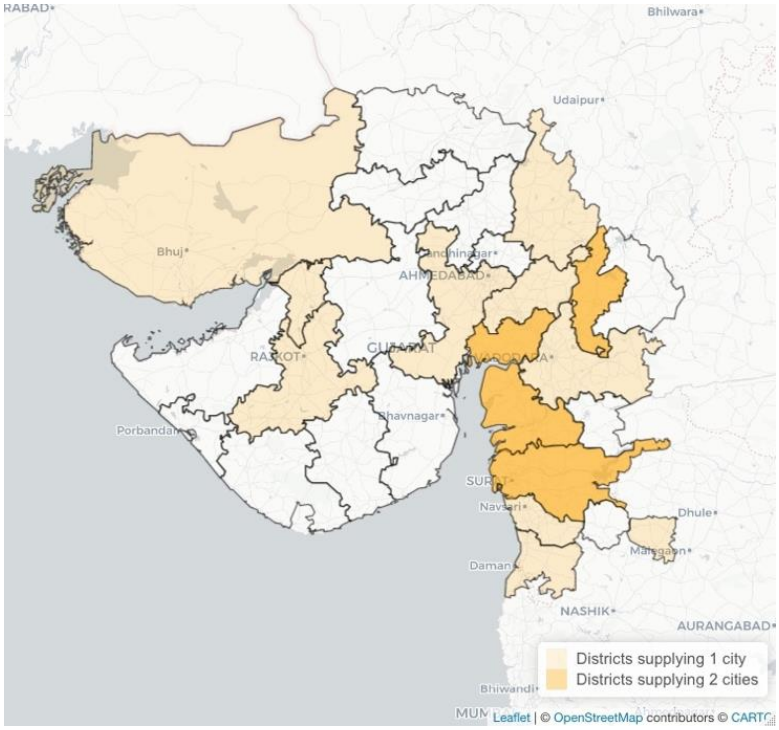

Figure 24. Catchment areas represented according to the number of cities they are supplying. Ten of the represented districts supply only one city (yellow) while four supply two cities (orange).

3. Definition of risk pathways for disease introduction and transmission

Any given pathogen can, at any time, contact with a susceptible bird from the farm to the shop, leading to a shop's primary case. To understand the nature of the risk, several shop's management and trading practices were identified as having a possible influence on pathogen introduction into live poultry shops (Release or introduction assessment) or transmission within live poultry shops, either to other birds (Animal exposure assessment) or to humans (Human exposure assessment).

Figure **25** and Figure 26 illustrate the variables linked to, respectively, the release and exposure pathways into LBSs in Gujarat, for pathogens in general.

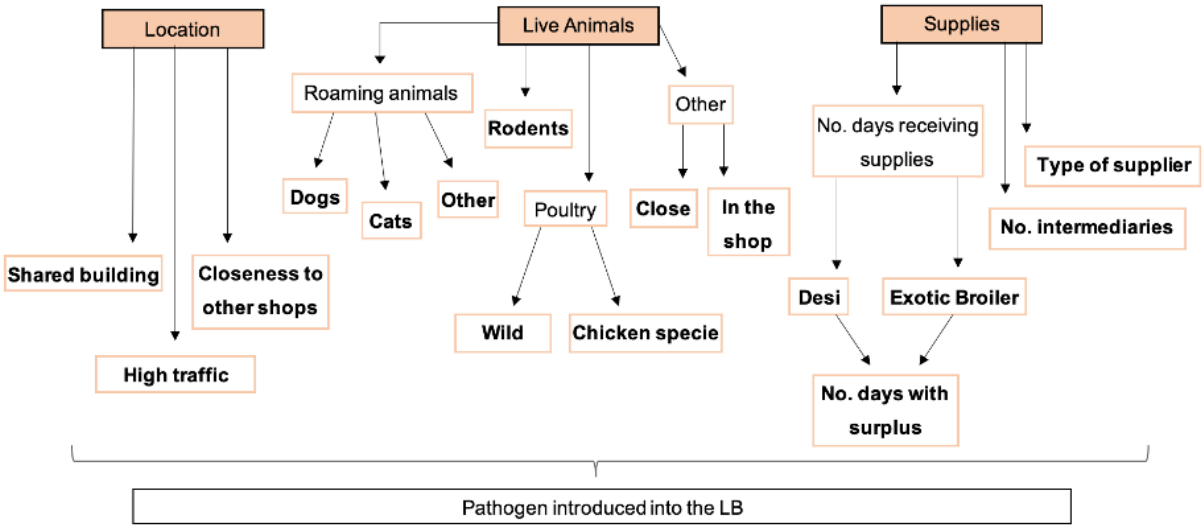

Figure 25. Diagram of variables linked to the release pathways of a pathogen into the live bird shops of Gujarat.

Seventeen variables were identified as potential risk factors for the release of a pathogen into live poultry shops. These variables were grouped in three main categories, including (i) Location of the shops, (ii) Live animals present or close to the shop (includes chicken species, wild birds, roaming animals, rodents and others) and (iii) Supplies (

Figure **25**).

The variables considered to represent a risk factor relevant for exposure of susceptible poultry and/or humans within the LBSs were 31 in total. Risk factors for disease transmission to humans included not only pathways for exposure in the shop but also regarding consumers. Three main categories encompassed all the referred variables, including (i) Housing characteristics, (ii) Poultry management practices and handling and (iii) Hygiene conditions of the shops (Figure 26).

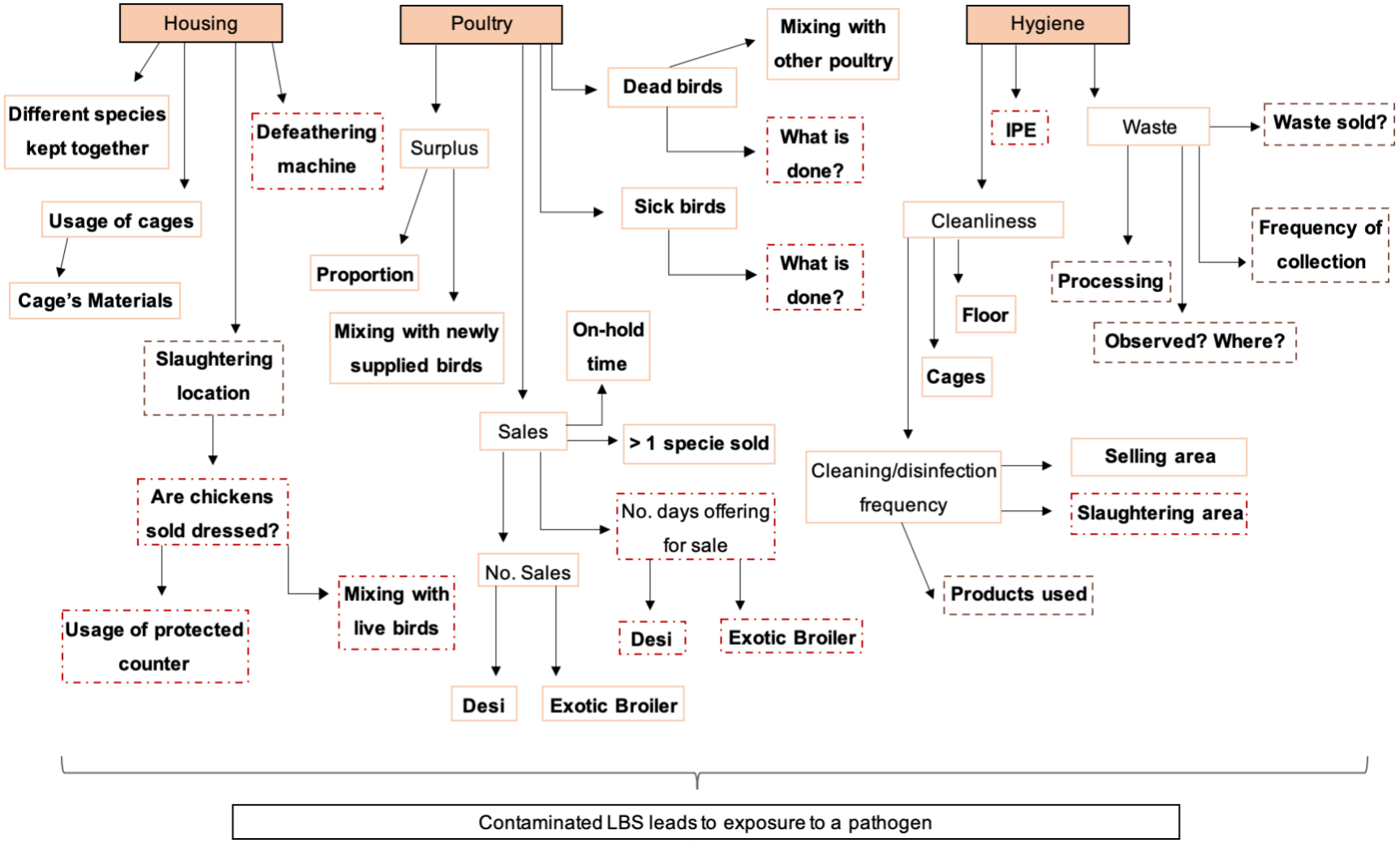

Figure 26. Diagram of variables linked to the exposure pathways for a pathogen within live poultry shops of Gujarat. Rectangles with different borders refer to distinct release assessments. Legend: continuous line – Animal exposure; intermittent dashed lines - Human exposure; dashed lines – Animal and Human exposu

4. Social network analysis

The social network analysis (SNA) conducted for Exotic Broiler shops in Gujarat suggests that the transport of chickens, from farms to shops, typically involves one (n= 99, 85.3%) or two intermediaries (n=12, 10.3%). In a smaller percentage, chickens are supplied directly from the farm with no intermediaries involved (n=5, 4.3%).

One to nine farms were identified as suppliers for the surveyed LBSs, considering their last day of purchases. For half of the LBSs (n=24, 50%) only one farm was identified, followed by two farms (n=9, 18.8%), four farms (n= 4, 8.4%), three, five or six farms (n= 3, 6.2% each) or, less commonly, from seven or nine farms (n=1, 2.1% each).

Figure 27 describes the connectivity between LBS's cities and catchment areas or districts.

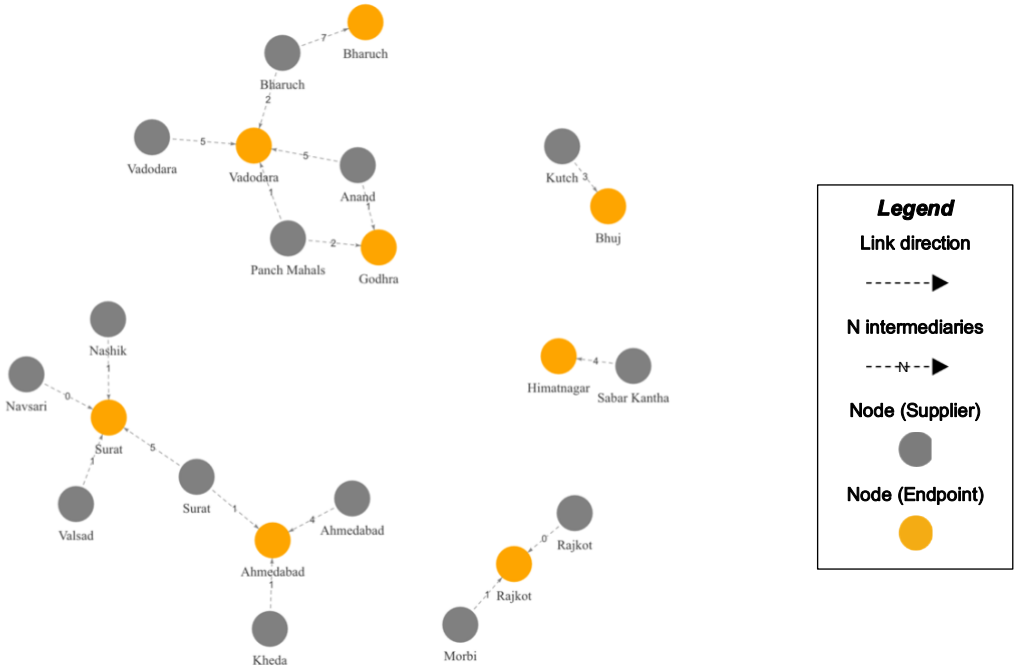

Figure 27. Poultry trading network for Exotic Broiler in Gujarat. Nodes (supplied cities and districts of origin) are represented with circles and each directed link with an arrow (from the chicken origin to the endpoint). For each arrow linking two locations, the total number of intermediaries is mentioned.

The studied network includes a total of twenty-three nodes, which include fourteen districts of origin and the eight cities where the surveyed shops are located. The network density is 16,1%, considering a total of 112 potential connections considering a directed network.

The largest weakly connected component (LWC) encompasses 34.8% (8/23) of the nodes. Within the largest weak component, tribal (Surat) and non tribal cities (Ahmedabad) connect with each other and share common intermediaries (including traders from Bharuch, Panch Mahals and Anand districts). The smallest components of the network, which include only two up to three nodes, comprised of 66.7% (2/3) of tribal cities and 33.3% (1/2) of non tribal cities.

Vadodara and Surat cities revealed higher in-degree values compared with other cities, which means they receive suppliers from a greater number of locations. On the other hand, Anand, Bharuch, Panch Mahals and Surat districts showed the highest out-degree values, although each of them only supplies two different cities.

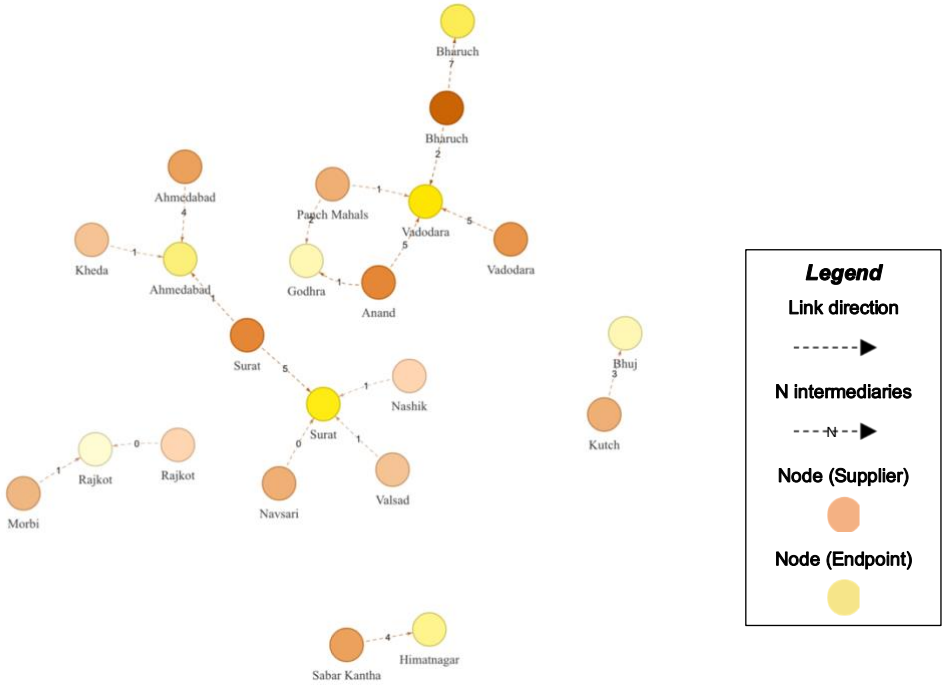

Figure 28. Definition of nodes according to the in- and out-strengths, or weighted degrees, within the Exotic Broiler's trading network. Supplying districts and respective out-degrees are represented in yellow and cities where shops are located in orange. Higher intensity of colours reflects higher in- and out-strengths, respectively for cities and districts. For each arrow linking two locations, the total number of intermediaries is mentioned.

Figure 28 shows the city and district with the highest in- and out-strengths, respectively. The city with the highest in-strength considering all the components, or largest number of intermediaries coming from its supplying cities, is Vadodara (supplied by a total of 13 intermediaries). Similarly, Bharuch is the district with the biggest number of intermediaries supplying from its farms or highest out-degree (total of 9 intermediaries). These two locations do not belong to the LWC. Within the LWC, Surat is the city with the highest in-strength (supplied by a total of 7 intermediaries) and Surat district has the highest out-strength (6 intermediaries).

VI. Discussion

The current survey study included 86 participants and had a high response rate of about 97.7% (1 individual refused to participate and 1 other participant did not complete one of the questionnaires). Most participants had at least finished lower secondary school (62, 72.1%)

and represented the youngest group in the study, while most of the illiterate (11,12.8%), were adults with more than 35 years old. These numbers may reflect an investment into younger and more educated participants engaging in agricultural and livestock areas, which allows for a higher receptivity towards new information and ideas.

Education and literacy disparities between urban and rural populations are accentuated, with much higher rates of illiteracy in rural areas than more urban areas (UNESCO 2014). This study did not show a percentage as high as it could be expected for illiterate individuals since urban and peri urban were the only represented areas. Improving the education of poultry industry populations, not only men but also women, increases the efficiency of the market and contributes to an improved health of both families and their poultry.

Live bird shops are known to facilitate the movement of poultry and its products through networks that can span large geographical areas and, therefore, understanding live poultry trade patterns provides valuable information concerning the likelihood of disease introduction and/or spread. To the best of our knowledge, this study represents the first assessment of poultry trading practices and networks in India, and specifically in Gujarat.

1. Pathogen risk pathways

1.1. Risk of introduction

The contact with a susceptible bird can either happen due to the introduction of another infectious chicken, a trader as an infectious carrier or another animal species in the premises also acting as carriers. Factors as the location of the shop, presence of other animals and how supplies are managed can influence the release of a pathogen into the shop (

Figure **25**).

The higher numbers of shops sharing their buildings, with other shops in their close vicinity and close to high traffic streets are factors that create opportunities for dense concentration of a large number of species (Galindo-González 2020), bringing several concerns regarding the possibility of introduction of pathogens, either by direct contact with a carrier or a fomite (FAO 2011). The selected live poultry shops were rather small businesses, with a median of two workers (interquartile range 1-3). Most sites had other LBSs in their vicinity (57.0%), although only a part of the shops was in their direct neighbourhood (25.7%). Nevertheless, more than 80% of the shops were located in a street with high traffic, which creates large opportunities for contact and can facilitate disease introduction in case of an outbreak. Restricting unnecessary traffic around the shops, or introducing physical barriers that prevent undesired movements, should be a priority as part of an effective biosecurity plan to reduce the risk of introduction of a pathogen in the shops.

Similarly, the presence of different animal species being sold or close to the shop, possibly from different origins, can heighten the chances of contact between chickens and potential carriers of disease, not only for the respective shop but also for the others in its vicinity (Peiris and Yen 2014).

From the data collected, EBs were the main poultry species being sold by interviewed traders (83.7% versus 70.1% selling Desi) although the greater part of the shops sell both chicken breeds, either in tribal and non tribal cities. As expected, the number of LBSs selling Desi was more pronounced in tribal areas, where traditional systems with low biosecurity are more likely to be found (TISS 2009). Quails and pigeons were also reported to be sold but only in a few shops, which goes in accordance with recent reports on Gujarat's poultry population (DAHDF 2019). When different poultry species are sold in the same shop, they are not often kept in close or direct contact with each other, which prevents further contact and transmission of pathogens between species.

The percentage of shops selling other animals and/or observed animals around the shop were rather small but should not be ignored. Roaming animals were sometimes seen in the shop area, many times in close contact with the poultry, representing a risk factor for disease introduction directly in the LBSs, as they are frequently carriers of poultry diseases. For instance, many dogs and cats are asymptomatic carriers of *Salmonella enteritidis*, which can be transmitted to poultry and are often linked to illness in humans sharing the same household (Yang et al. 2017). Moreover, the presence of rabbits in the shops was also mentioned to increase the risk of a market to be found positive to avian influenza viruses (Bulaga et al. 2003). This could happen due to a factor directly related with the rabbits but there is little research on the role of rabbits in avian influenza transmission. Even though most of the LBS do not sell other animal species in their facilities, seafood, goats, sheep, buffaloes or wild birds were mentioned to be sold in a smaller percentage of the shops (31.4%) or in their 100 meters vicinity (23.3%). Once more, the presence of potential carriers should be perceived as they can contribute to the introduction of disease-causing agents. Wild birds, which were seen to be in close contact with 4 of the shops (4.7%) and are sold in the shop's vicinity of 1 shop, should be perceived as a particular threat as they can be carriers of important diseases transmissible to poultry (Thomas et al. 2008). These birds are the main reservoir for low pathogenic avian influenza A viruses, from which occasional spill over to poultry occurs and possibly a turn into a highly pathogenic avian influenza A viruses (Keawcharoen et al. 2011; Bodewes and Kuiken 2018). Although in most part of the cases (77.9%) poultry are kept in cages, they are regularly housed in front of the shop (50.0%) and in close contact with each

other, requiring an additional attention to the environment and prevention of access of other animals to the shop's premises.

As previously mentioned, the high frequency and volume of surplus birds can greatly influence the risk of disease introduction, by increasing the time poultry are kept in the shop and possibly mixing with newly supplied birds (Offeddu et al. 2016; Chowdhury et al. 2020). In the surveyed shops, leaving unsold chickens was found to be a common occurrence in both frequency and volume, which increases the time spent by poultry in the LBS system and make infection of susceptible birds more likely to happen. The proportion of unsold chickens can be as high as 45.2% or even 92.3%, respectively for EB and Desi species. The big proportions of unsold Desi might have to do with the low volume of sales concerning this species and can also reveal a change on the consumer's purchasing behaviour, when opting for other than local species. In this study, unsold poultry are kept in the shop during the night for most of the shops which means there are high chances of mixing of birds. A study in China found that banning overnight poultry storage reduced H9N2 virus isolation in chickens (Connie Leung et al. 2012). Nevertheless, this interpretation would only be possible if considering the frequency and time of the day when newly supplied birds are obtained.

1.2. Risk of transmission

Once there is a susceptible bird in the shop, a shop's primary case can surge and possibly become infectious, depending on the latent period for any given disease. This first case can cause the spread of the infection to the flock and, possibly, in zoonotic incidents (Figure 26).

1.2.1. Animal-to-animal transmission

The effect of incursion of a pathogen among birds is likely to be influenced by housing characteristics of the shop. Even though it is not frequent to see shops keeping different bird species together (34.9%), there are still high chances of transmission between animals when species are kept in cages (77.8%) with limited space and close contact with birds in the same area. Metal is the most frequent material of the cages, which remarkably increases the potential for a pathogen to survive on its surface when comparing with other options, such as wood structures or even plastic (Koch et al. 2002).

Some poultry management practices can also bring several concerns. The volume of sales for each chicken type, which was extremely variable for the surveyed shops, can influence the risk of disease transmission between animals within the shops, given that more chickens sold mean less time spent in the store and lower density of birds in the same space (Lau et al. 2007). At the same time, the proportion of unsold chickens for the interviewed shops reached

considerable numbers, which can *per se* mean that more chickens will have to be kept together. Depending on whether chicken supplies are bought on the day they are offered for sale or the day before, the length of on-hold time can vary and chances of mixing unsold birds with newly supplied chickens can be increased. In the present study, most of the supplied birds arrive at the shop in the morning but some of the shops receive birds before opening time or even at night, creating opportunities for contamination of spaces in case there is an infected animal and, possibly, resulting in the exposure of other birds to a given pathogen (Connie Leung et al. 2012; Chowdhury et al. 2020).

In terms of hygiene practices, even though all the shops reported to disinfect their selling area every day, which is known to decrease environmental contamination (Bulaga et al. 2003; Trock et al. 2008), some of them (16.3%) only do this procedure once a day. These LBSs are more likely to have contaminated spaces and higher risk of exposure to a pathogen for birds in the shop, considering that the higher the frequency of cleaning, the lower the risk of exposure to a given pathogen (Carron et al. 2017). None of the shops reported to practice weekly or monthly rest days, except for one of the shops where a single rest day is applied on Sundays. This fact might increase the risk for pathogen circulation and amplification in the shops (Bulaga et al. 2003; Offeddu et al. 2016). Most of the shops reported to do sanitation strategically at different times of the day, including at opening hours, closing time and evening, reducing the capability of a pathogen to amplify in the environment (Chowdhury et al. 2020). Although cleaning is done with very basic equipment, the floor looked recently clean most of the times (82.6%), especially when it comes to shops using cages (85.7%).

1.2.2. Animal-to-animal and Human transmission

Regarding possibilities of transmission of a pathogen to both animals and Human, it is important to consider that, in many shops, poultry are slaughtered inside its facilities and that waiting and slaughtering areas frequently share the same space. Contaminated areas inside the shop that are close to the selling area can not only represent a risk for animal exposure but can also pose a risk for food borne diseases associated with contamination of dressed chickens (Indriani et al. 2010; Chowdhury et al. 2020).

Regarding waste management practices, it is known that the waste is collected every day but not what is done with it in a considerable part of the shops (64%). Waste can be a source of contamination and if kept in the shop can increase the risk of exposure for both animals and Human, especially if it was originated from slaughtering and processing procedures. The contamination to Human can be expected to happen not only by respiratory routes, since slaughtering generates droplets that might contain pathogen particles, but also by exposing

the carcasses to potentially high pathogen loads (Indriani et al. 2010). For more than 90% of the shops, nevertheless, waste from these areas was immediately thrown in a bin but there is no information on when it is collected and by whom.

1.2.3. Animal-to-Human transmission

Similarly, some practices may play a particularly important role in the transmission of pathogens to Human. Potential ways of transmission vary depending on the nature of the contact and have been suggested to include inhalation, ingestion, conjunctival, oral contact or intranasal inoculation, for example for H5N1 (Van Kerkhove et al. 2011).

The number of days and frequency of sales can increment the risk for humans to get exposed to a pathogen that was already at the shop or in an infected carcass.

Around 70% of the surveyed shops reported to sell dressed chickens but only a minority owns defeathering machines (5.8%), suggesting that manual defeathering is a common practice. This procedure can bring a problem of cross-contamination between workers, equipment and contaminated carcasses if the technique is not precise. This can happen, for example, by cutting and tearing of viscera or even by generating aerosols, which result in a higher risk of transmission to workers, for example of H5N1 (Van Kerkhove et al. 2011; Chowdhury et al. 2020). The slaughtering area, similarly, is cleaned every hour. However, most shops use only very basic equipment for sanitation, such as manual tools, making harder to maintain a risk-free environment. Moreover, individual protection equipment was rarely used by most of the workers, also increasing the risk of their exposure to pathogens when manipulating animals in the shop (Van Kerkhove et al. 2011).

At the same time, the biggest percentage of the shops do not have the waiting and slaughtering areas separated from the selling area. Under such scenario and given that poultry is mainly slaughtered inside the shop (for 82.6% of the LBS), there is a higher potential for maintenance and amplification of pathogens in the environment (Indriani et al. 2010). This can be especially relevant for shops that do not clean and disinfect the area frequently, in particular for the ones that reported to only clean it thrice, twice or once daily (38.4%). The number of times poultry is slaughtered should also be considered to measure the impact that this practice can have in the prevention of disease transmission.

The descriptive analysis conducted suggests that there are several practices that may promote pathogen amplification and persistence within the LBSs in Gujarat and consequent transmission to poultry and human populations.

2. Connectivity between the surveyed shops through live poultry trade

All the eight selected cities get most of their supplies from the main poultry pockets in Gujarat, which represent zones with a high density of poultry farms (Biotechnology Research Center 2012). Most EBs were sourced from traders or other farms in their surrounding districts, except Ahmedabad and Surat. Ahmedabad not only receives supplies from its closest districts (Kheda and Ahmedabad), which are themselves zones with a high density of poultry farms (especially Kheda), but also from Surat. This city was expected to experience a high inflow of chickens, given that Ahmedabad is the largest city of the state. The same happens with Surat, the largest city in South Gujarat, which gets poultry from the surrounding tribal zones (Navsari and Valsad) and Nashik district, the closest state in the neighbourhood. Although Surat city does not fall under the tribal area, it has been considered in that category since Surat district has the highest number of tribal talukas in Gujarat (OHPH 2020). Vadodara, the largest city in Middle Gujarat, showed the highest number of supplying districts, comprising of four different regions that include the main poultry pocket of Gujarat. The city receives not only poultry from Bharuch, Panch Mahals and Vadodara districts, but also from Anand, which has the highest number of broiler farms in Gujarat (Biotechnology Research Center 2012).

Four of the 14 considered districts supplied more than one city. Districts supplying both tribal and non-tribal cities happened to be located exclusively in Middle and South Gujarat, while the ones supplying tribal cities tend to occupy a much wider area, including not only the Middle and South Gujarat but also the North zones and South Saurashtra. Districts with tribal administrative headquarters either supply tribal or non tribal cities, but the same does not happen for districts with non tribal administrative headquarters (Figure 23).

The degree of connectedness of poultry networks, defined as the frequency with which links between poultry production premises, traders and LBSs are made via people, animal movement and/or sharing of equipment, influences the potential for wide spread of disease (Moyen et al. 2018). Despite recruited LBSs being scattered throughout 8 cities, most of them were connected to one another through the movements of traders, connecting both tribal and non tribal cities. Yet, the overall connectivity between nodes was not high with an overall low density.

It appeared that most LBSs with higher volume of sales are mainly located in the cities that belong to the components in the network with stronger connections to other shops through the movements of their traders. Those include two strongly connected cities, namely Vadodara and Bharuch, which is also the city that receives the highest number of traders from a single location. Ahmedabad and Surat are also two of the cities that belong to the GSC and were observed with a high turn-over of chickens. It is also important to consider that, although in a

small proportion, some of these nodes reported to carry their sales to other traders, increasing the risk of transmission of a pathogen within the network component if there is an infected bird.

Regarding the strength, Vadodara city and Bharuch district were the nodes with the highest in- and out-strengths, respectively considering de number of intermediaries to and from each location. The higher the number of intermediaries, the greater the chances that a trader gets its supplies from an infected flock and higher the probability of introduction of an infectious bird into a LBS. Shops that had two intermediaries over just one are more likely to be risk nodes. Therefore, Baruch district and Vadodara city should be considered as critical control points and targeted for risk mitigation measures. Besides, most of the reported shop suppliers include mobile traders that come directly to the shop (54.0%), which heightens the potential for contamination through close contact.

The network in this study, regarding EB species, suggests that the overall network of contact between LBSs was heterogeneous, with LBSs being preferably connected to others located in their vicinity (Figure 22). The predominance of local connections between shops may suggest a likelihood for spatial wave-like spread of pathogens through this network, which in certain way can limit the potential for disease to be transmitted in large scale. Regardless, this network connects distant poultry populations, that include not only tribal but also non-tribal areas, increasing the risk of pathogen spread from regions that sometimes have poorest biosecurity levels. Assessing the impact of the extent of trader movements on the structure of the network that they shape, and, therefore, the dynamics of diseases spreading through it, would need to be further studied.

3. Limitations and future perspectives

The results should be interpreted taking account the study's assumptions and limitations. To start, although interview-based surveys are widely used to capture a variety of relational data, they also have several limitations. Conducting interview studies can be time-consuming, recall bias can interfere with responses there are not always precise and sometimes they are dependent on the ability of the interviewer. There could also be interpretation issues and there is less anonymity, which sometimes is a big concern for the respondents resulting in biased answers. In this survey, one participant in a shop refused to participate and another one did not complete the questionnaire.

Moreover, the usage of spatial sampling methods usually involves a random selection of clusters, within which endpoints are selected. This method can lead to underrepresentation in regions with highly heterogeneous populations or development patterns, which is why the cities were firstly purposively selected. Nevertheless, this method introduces opportunities for a more

efficient sampling and reduces the potential for bias in resource-constrained scenarios when selecting starting points. At the same time, it provides the fastest and easiest method for data collection for field survey teams (Grais et al. 2007; Maduekwe and de Vries 2019).

For the selection of traders, snowball sampling was used as a network-based technique that relies on existing participants to recruit future respondents for an investigation, being particularly useful when it is anticipated that individuals may be reluctant to be identified (Dragan and Isaic-Maniu 2013). Since it is based on networks and relationships, it may lend credibility and efficiency to the research by selecting people from established social networks of people with characteristics of interest (Shaghaghi et al. 2011). However, oversampling of a particular network of peers can lead to bias, asking the respondents to provide names of peers might raise ethical concerns and there is no guarantee about the representativeness of the sample. It is also not possible to determine the sampling error and make statistical inferences from the sample, due to the absence of random selection samples. Nevertheless, the technique is fairly preferred when doing qualitative research and especially for the recruitment of participants when researchers cannot afford resource intensive sampling approaches (Valerio et al. 2016; Tyrer and Heyman 2016).

The full network for EBs was not possible to obtain since for 37.5% of the shops, the farm location could not be identified and, therefore, they were not considered in the social network analysis. Likewise, the impact of the removal of these nodes on network connectedness could have been underestimated. Moreover, for most of the final suppliers, only information on talukas was available and not the exact farm location, which were offset by considering only district level to estimate approximate network patterns.

Temporal variations in trading practices or network structure were not identified neither reported in the present study. However, it was recognised that the number of traded poultry can substantially increase in multiple settings, including seasonal and religious festivals (for example, Chinese New Year and Ramadan). Studies not only reported an increase in the number of poultry sold but also a switch in the number of links in the network as well as distances over which poultry is traded (Van Kerkhove et al. 2009; Soares Magalhães et al. 2012; Delabouglise et al. 2017). Such variations are likely to happen in India as well, not only during Christmas and New Year's Eve but also Pongal festivities. Further investigations should aim at quantifying temporal variation in the networks' trading patterns to explore its potential impact in disease spread. Moreover, several studies have referred COVID-19 to severely affect numerous economic sectors across the world, including livestock production (Chapot et al. 2021; Sattar et al. 2021). Inevitably and as main livestock sector in India, poultry production and trade were greatly impacted, with poultry meat prices falling nearly 10 percent (FAO

2020b). Although the current study was carried out during the COVID-19 pandemic, impacts or variations were not investigated.

It is also relevant to consider that investigation of risk pathways in the present study was conducted precociously and factor analysis followed by multivariate analysis were not proceeded to classify the shop by risk, which limits the one's capacity to correlate observed variables and describe its variability.

In the future, this network can be completed by adding Desi trade to evaluate whether connectivity is increased between nodes. Further investigation on risk pathways for disease transmission should also be carried and identification of their geographical and socio-economic determinants, by conducting a multivariate analysis (MVA), are some of the steps that could vastly benefit these networks. To finish, it would also be interesting to characterise the identified farms and understand whether large farmers and small farmers supply the same or different areas.

VII. Conclusion

In conclusion, the descriptive analysis conducted suggests that poultry trade practices varied according to the poultry types considered and a high heterogeneity was observed in the scale of operations. The described practices may promote pathogen amplification and persistence within the LBSs in Gujarat.

Moreover, the network shaped by poultry movements, regarding EB chickens, connect distant poultry populations that include both tribal and non-tribal areas, increasing the risk of pathogen spread in the region. Nevertheless, most of the surveyed cities get their supplies from the closest district(s).

The published literature in veterinary epidemiology typically focuses on assessing the impact of network structure on disease dynamics, but the anthropogenic dimension of poultry trade is still poorly understood. Human behaviours are dynamic and an intrinsic part of epidemiological systems, however, the impact that an alteration in these systems can cause and how behaviours adapt in this scenario are often ignored. More studies should be done to investigate the way in which disease dynamics and other forces that alter trading practices have an effect on network structure. SNA techniques help building and analysing the network of poultry movements to identify high-risk premises and offer new insights on disease transmission dynamics, making it possible to develop more effective strategies for disease control.

Understanding human behaviours in PDNs, with emphasis on behaviours that can moderate or exacerbate risk and people's perception of risks, what are its drivers and how to

influence them plays an important role for disease prevention and control. Moreover, careful targeting of surveillance and control programmes are of particular importance in areas where live poultry trade is widespread, involves many actors and where live bird markets are ubiquitous. This process will only be possible through an interdisciplinary approach involving many scientific disciplines, including veterinary epidemiologists, microbiologists, sociologists, anthropologists and economists.

VIII. Bibliography

Almende B, Thieurmel B, Robert T. 2021. Package ‘ visNetwork .’

Amestoy PR, Azzalini A, Badics T. 2020. Package ‘ igraph .’

Attri S, Tyagi A. 2013. Climate profile of India. Meteorol Monogr.(2).

Belwal LM. 2016. H9N2 low pathogenic avian influenza in India – a simmering inferno? Int Hatch Pract. 31(2):11–13.

Bera A, Bhattacharya D, Pan D, Dhara A, Kumar S, Das S. 2010. Evaluation of Economic Losses due to Coccidiosis in Poultry Industry in India. Agric Econ Res Rev. 23(1):91–96. https://www.indianjournals.com/ijor.aspx?target=ijor:aerr&volume=23&issue=1&article=010.

Bharti V. 2016. Situational Analysis of Ashram Schools in Maharashtra: In the Context of Child Protection. Mumbai, India.

Biotechnology Research Center. 2012. A detailed report on poultry distribution in Gujarat, India.

Bivand R, Lewin-Koh N. 2021. Package ‘ maptools .’

Bodewes R, Kuiken T. 2018. Changing Role of Wild Birds in the Epidemiology of Avian Influenza A Viruses. Adv Viral Res. 100:279–307.

Bulaga L, Garber L, Senne D, Myers T, Good R, Wainwright S, Trock S, Suarez D. 2003. Epidemiologic and surveillance studies on avian influenza in live-bird markets in New York and New Jersey. Avian Dis. 47(SPEC. ISS.):996–1001. doi:10.1637/0005-2086-47.s3.996.

Butts CT. 2020. Package ‘ sna .’

Carron M, Alarcon P, Karani M, Muinde P, Akoko J, Onono J, Fèvre EM, Häsler B, Rushton J. 2017. The broiler meat system in Nairobi, Kenya: Using a value chain framework to understand animal and product flows, governance and sanitary risks. Prev Vet Med. 147(August):90–99. doi:10.1016/j.prevetmed.2017.08.013. https://doi.org/10.1016/j.prevetmed.2017.08.013.

Chapot L, Whatford L, Compston P, Tak M, Cuevas S, Garza M, Bennani H, Aslam H Bin, Hennessey M, Limon G, et al. 2021. A global media analysis of the impact of the covid-

19 pandemic on chicken meat food systems: Key vulnerabilities and opportunities for building resilience. Sustain. 13(16). doi:10.3390/su13169435.

Chatterjee RN, Rajkumar U. 2015. An Overview of Poultry Production in India. Indian J Anim Heal. 54(2):89–108.

Cheng J, Karambelkar B, Xie Y. 2021. Package ‘ leaflet .’ https://rstudio.github.io/leaflet/.

Chinnasamy P, Hubbart JA, Agoramoorthy G. 2013. Using remote sensing data to improve groundwater supply estimations in Gujarat, India. Earth Interact. 17(1):1–17. doi:10.1175/2012EI000456.1.

Chowdhury S, Azziz-Baumgartner E, Kile JC, Hoque MA, Rahman MZ, Hossain ME, Ghosh PK, Ahmed SS, Kennedy ED, Sturm-Ramirez K, et al. 2020. Association of biosecurity and hygiene practices with environmental contamination with influenza a viruses in live bird markets, bangladesh. Emerg Infect Dis. 26(9):2087–2096. doi:10.3201/eid2609.191029.

CIET. 2019. India: Size and Location. :5–7. https://epathshala.nic.in/topic.php?id=0968CH01.

Conan A, Goutard FL, Sorn S, Vong S. 2012. Biosecurity measures for backyard poultry in developing countries: A systematic review. BMC Vet Res. 8. doi:10.1186/1746-6148-8-240.

Connie Leung Y, Lau EH, Zhang LJ, Guan Y, Cowling BJ, Peiris J. 2012. Avian influenza and ban on overnight poultry storage in live poultry markets, Hong Kong. Emerg Infect Dis. 18(8):1339–1341. doi:10.3201/eid1808.111879.

DAHDF. 2012. 19th Livestock Census. Ministry of Agriculture and Farmers Welfare, Government of India.

DAHDF. 2016. Incidence of livestock diseases in India during 2015 and 2016. India.

DAHDF. 2018. The Poultry Industry in India. Mahdi SS, editor. Minist Agric. 1(1):130. doi:10.1891/9780826190123.ap02. http://www.dadf.gov.in/sites/default/filess/20th Livestock census-2019 All India Report.pdf.

DAHDF. 2019. 20th Livestock Census. Minist Agric.:130. http://www.dadf.gov.in/sites/default/filess/20th Livestock census-2019 All India Report.pdf.

Delabouglise A, Choisy M, Phan TD, Antoine-Moussiaux N, Peyre M, Vu TD, Pfeiffer DU, Fournié G. 2017. Economic factors influencing zoonotic disease dynamics: Demand for

poultry meat and seasonal transmission of avian influenza in Vietnam. Sci Rep. 7(1):1–14. doi:10.1038/s41598-017-06244-6.

Dikid T, Jain S, Sharma A, Kumar A, Narain J. 2013. Emerging & re-emerging infections in India: An overview. Indian J Med Res. 138(JUL 2013):19–31.

Dowle M, Srinivasan A. 2021. Package “data.table.” https://r-datatable.com.

Dragan I-M, Isaic-Maniu A. 2013. Snowball Sampling Completion. J Stud Soc Sci. 5(2):160–177. https://www.semanticscholar.org/paper/Snowball-Sampling-Completion-Dragan-Isaic-Maniu/bdda0e55ed546291f6533cfe9fb461778a59ade5.

FAO. 2008a. Poultry in the 21st Century: avian influenza and beyond. In: Olaf Thieme; Dafydd Pilling, editor. International Poultry Conference. Bangkok, Thailand.

FAO. 2008b. Poultry Sector Country Review - India.

FAO. 2011. A value chain approach to animal diseases risk management. http://arjournals.annualreviews.org/doi/full/10.1146/annurev.economics.050708.143235?select23=Choose.

FAO. 2013. Poultry Development Review.

FAO. 2020a. Meat and Meat products. FAO.

FAO. 2020b. Meat market review. http://www.fao.org/3/ca3880en/ca3880en.pdf.

Fournie G, Guitian J, Desvaux S, Cuong VC, Dung DH, Pfeiffer DU, Mangtani P, Ghani AC. 2013. Interventions for avian influenza A (H5N1) risk management in live bird market networks. Proc Natl Acad Sci U S A. 110(22):9177–9182. doi:10.1073/pnas.1220815110.

Fournié G, Pfeiffer DU. 2013. Monitoring and controlling disease spread through live animal market networks. Vet J. 195(1):8–9. doi:10.1016/j.tvjl.2012.09.014.

Fournié G, Tripodi A, Nguyen TTT, Nguyen VT, Tran TT, Bisson A, Pfeiffer DU, Newman SH. 2016. Investigating poultry trade patterns to guide avian influenza surveillance and control: A case study in Vietnam. Sci Rep. 6(July):1–10. doi:10.1038/srep29463. http://dx.doi.org/10.1038/srep29463.

Galindo-González J. 2020. Live animal markets: Identifying the origins of emerging infectious diseases. Psychiatry Res. 14(4)(January):293.

Ghosh R, Uppal B, Aggarwal P, Chakravarti A, Jha AK. 2013. Increasing antimicrobial resistance of campylobacter jejuni isolated from paediatric diarrhea cases in a tertiary care hospital of New Delhi, India. J Clin Diagnostic Res. 7(2):247–249. doi:10.7860/JCDR/2013/5267.2738.

Grais RF, Rose AM, Guthmann JP. 2007. Don't spin the pen: Two alternative methods for second-stage sampling in urban cluster surveys. Emerg Themes Epidemiol. 4:1–7. doi:10.1186/1742-7622-4-8.

Husain M. 2014. Geography of India.

IANS. 2006. India's bird flu vaccine at just 35 paise! Hindustan Times.

ICAR-DPR. 2008. Vision 2050. Vis 2050.:1–13. doi:10.1007/978-4-431-09431-9.

IFPRI. 2019. Gujarat. Partnerships Oppor to Strengthen Harmon Actions Nutr India. [accessed 2021 Jul 9]. https://poshan.ifpri.info/2019/04/26/gujarat/#:~:text=Gujarat%2C situated on the west coast of India%2C,people %285 percent of the population of India%29.

Indriani R, Samaan G, Gultom A, Loth L, Irianti S, Adjid R, Dharmayanti NLPI, Weaver J, Mumford E, Lokuge K, et al. 2010. Environmental sampling for avian influenza virus a (H5N1) in live-bird markets, Indonesia. Emerg Infect Dis. 16(12):1889–1895. doi:10.3201/eid1612.100402.

Jahnabi J, Buragohain R. 2018. Control of Infectious Diseases in Livestock Farms: Strategies to be Adopted Under Indian Perspective - Review. Int J Curr Res Rev. 10(14):4–8. doi:10.31782/ijcrr.2018.10142.

Kasssambara A. 2020. Package ' ggpubr .' https://rpkgs.datanovia.com/ggpubr/.

Keawcharoen J, Van Den Broek J, Bouma A, Tiensin T, Osterhaus AD, Heesterbeek H. 2011. Wild birds and increased transmission of highly pathogenic avian influenza (H5N1) among poultry, Thailand. Emerg Infect Dis. 17(6):1016–1022. doi:10.3201/eid1705.100880.

Van Kerkhove MD, Mumford E, Mounts AW, Bresee J, Ly S, Bridges CB, Otte J. 2011. Highly pathogenic avian influenza (H5N1): Pathways of exposure at the animal-human interface, a systematic review. PLoS One. 6(1):1–8. doi:10.1371/journal.pone.0014582.

Van Kerkhove MD, Vong S, Guitian J, Holl D, Mangtani P, San S, Ghani AC. 2009. Poultry movement networks in Cambodia: Implications for surveillance and control of highly pathogenic avian influenza (HPAI/H5N1). Vaccine. 27(45):6345–6352.

doi:10.1016/j.vaccine.2009.05.004.

Koch AP, Kofod CJ, Konova D, Kvist KE, Lindegaard B. 2002. Wood, plastic and steel – a comparison of hygienic properties. https://www.fefpeb.eu/cms/files/2016-02/nordisk-industrifond-2002-wood-in-the-food-industry-wood-plastic-and-steel-no.-10-.pdf.

Kondo MC, Bream KD, Barg FK, Branas CC. 2014. A random spatial sampling method in a rural developing nation. BMC Public Health. 14(1):1–8. doi:10.1186/1471-2458-14-338.

Kumar N. 2007. Spatial sampling design for a demographic and health survey. Popul Res Policy Rev. 26(5–6):581–599. doi:10.1007/s11113-007-9044-7.

Kurscheid J, Stevenson M, Durr P, Toribio J, Kurscheid S, Ambarawati I, Abdurrahman M, Fenwick S. 2017. Social network analysis of the movement of poultry to and from live bird markets in Bali and Lombok, Indonesia. Transbound Emerg Dis. 64(6):2023–2033. doi:10.1111/tbed.12613.

Lau EH, Leung C, Li JZ, Cowling BJ, Sin PM, Guan Y, Leung GM, Peiris J. 2007. Effect of interventions on influenza A (H9N2) isolation in Hong Kong's live poultry markets, 1999-2005. Emerg Infect Dis. 13(9):1340–1347. doi:10.3201/eid1309.061549.

Maduekwe E, de Vries WT. 2019. Random spatial and systematic random sampling approach to development survey data: Evidence from field application in Malawi. Sustain. 11(24). doi:10.3390/SU11246899.

Martin V, Zhou X, Marshall E, Jia B, Fusheng G, FrancoDixon MA, de Haan N, Pfeiffer DU, Soares Magalhães RJ, Gilbert M. 2011. Risk-based surveillance for avian influenza control along poultry market chains in South China: The value of social network analysis. Prev Vet Med. 102(3):196–205. doi:10.1016/j.prevetmed.2011.07.007. http://dx.doi.org/10.1016/j.prevetmed.2011.07.007.

Mavalankar D V, Vora KS, Ramani K, Raman P, Sharma B, Upadhyaya M. 2009. Maternal health in Gujarat, India: A case study. J Heal Popul Nutr. 27(2):235–248. doi:10.3329/jhpn.v27i2.3366.

Moyen N, Ahmed G, Gupta S, Tenzin T, Khan R, Khan T, Debnath N, Yamage M, Pfeiffer D, Fournie G. 2018. A large-scale study of a poultry trading network in Bangladesh: Implications for control and surveillance of avian influenza viruses. BMC Vet Res. 14(1):1–12. doi:10.1186/s12917-018-1331-5.

Müller K, Wickham H. 2021. Package ' tibble .'

Newman M. 2018. Networks. Second Edi. Oxford, United Kingdom: Oxford University Press.

Offeddu V, Cowling BJ, Peiris J. 2016. Interventions in live poultry markets for the control of avian influenza: A systematic review. One Heal. 2:55–64. doi:10.1016/j.onehlt.2016.03.002. http://dx.doi.org/10.1016/j.onehlt.2016.03.002.

OHPH. 2020. The proposed selection of PDNs and nodes in Gujarat. Gujarat.

OIE. 2019. Terrestrial Animal Health Code.

One Health Poultry Hub. 2019. [accessed 2021 Jul 12]. https://www.onehealthpoultry.org.

ONU. 2018. Transforming Our World: The 2030 Agenda for Sustainable Development. A New Era Glob Heal. doi:10.1891/9780826190123.ap02.

ONU. 2019. World Population Prospects 2019. https://population.un.org/wpp/Download/Standard/CSV/%0Ahttps://population.un.org/wpp/Download/Files/1_Indicators (Standard)/CSV_FILES/WPP2019_TotalPopulationBySex.csv.

ORGI. 2011a. Census of India. India. [accessed 2021 Jul 19]. https://censusindia.gov.in/2011-common/censusdata2011.html.

ORGI. 2011b. State Primary Census Abstract for individual scheduled tribe. India.

ORGI. 2011c. Population Enumeration Data (Final Population). Census 2011. [accessed 2021 Jun 20]. https://censusindia.gov.in/2011census/population_enumeration.html.

Parashar S. 2021. Bird flu: Experts say India must legalise vaccination than resort to culling of birds. The Indian Express.

Patel B, Bhimani M, Bhanderi B, Jhala M. 2015. Isolation and molecular characterization of nephropathic infectious bronchitis virus isolates of Gujarat state, India. VirusDisease. 26(1–2):42–47. doi:10.1007/s13337-015-0248-x.

Peiris M, Yen H. 2014. Animal and human influenzas. OIE Rev Sci Tech. 33(2):539–553. doi:10.20506/rst.33.2.2289.

Pica-Ciamarra U, Otte J. 2010. Poultry, food security and poverty in India: Looking beyond the farm-gate. Worlds Poult Sci J. 66(2):309–319. doi:10.1017/S0043933910000358.

Rajendran P, Babji S, George A, Rajan D, Kang G, Ajjampur S. 2012. Detection and species identification of Campylobacter in stool samples of children and animals from Vellore, south India. Indian J Med Microbiol. 30(1):85–88. doi:10.4103/0255-0857.93049. https://doi.org/10.4103/0255-0857.93049.

Rajurkar G, Roy A, Yadav MM. 2010. Antimicrobial sensitivity pattern of Haemophilus paragallinarum isolated from suspected cases of infectious coryza in poultry. Vet World. 3(4):177–181.

Rebecca N, Moyen S. 2019. The potential role of live bird trade in avian influenza virus transmission in Bangladesh.

Rich K, Dizyee K, Huyen Nguyen T, Ha Duong N, Hung Pham V, Nga Nguyen T, Unger F, Lapar M. 2018. Quantitative value chain approaches for animal health and food safety. Food Microbiol. 75:103–113. doi:10.1016/j.fm.2017.09.018. https://doi.org/10.1016/j.fm.2017.09.018.

Robyn G. 2012. Challenges and opportunities for small-scale family poultry production in developing countries. World's Poult Congr. 20(February):5–9.

Rushton J, Pinto J, Taylor N. 2009. Linking value chain analysis with epidemiological risk analysis to improve disease prevention and control interventions. Proc Int Soc Vet Epidemiol Econ Durban.(1):10–14.

Sattar A Al, Mahmud R, Mohsin MAS, Chisty NN, Uddin MH, Irin N, Barnett T, Fournie G, Houghton E, Hoque MA. 2021. COVID-19 Impact on Poultry Production and Distribution Networks in Bangladesh. Front Sustain Food Syst. 5(August):1–12. doi:10.3389/fsufs.2021.714649.

Scott A, Chamberlain MS. 2021. Package ' geojsonio .' https://github.com/ropensci/geojsonio.

Shaghaghi A, Bhopal RS, Sheikh A. 2011. Approaches to Recruiting "Hard-To-Reach" Populations into Re-search: A Review of the Literature. Heal Promot Perspect. 1(2):86–94. doi:10.5681/hpp.2011.009.

Silva MV da. 2013. Poultry and poultry products - risks for human health. Poult Dev Rev FAO.:11–21. http://www.fao.org/docrep/019/i3531e/i3531e03.pdf.

Sindhi S, Mathapati B, Parmar V, Marandi S, Sumankumar M, Javia B, Ghodasara S, Kathiriya J, Bhedi K, Patel J. 2020. Prevalence of Campylobacter spp. Isolated from Poultry, Human and Environment in Junagadh District of Gujarat. Int J Curr Microbiol Appl Sci. 9(9):3319–3326. doi:10.20546/ijcmas.2020.909.413.

Singh M, Kaur P, Singla L Das, Kashyap N, Bal MS. 2021. Assessment of risk factors associated with prevalence of gastrointestinal parasites in poultry of central plain zone of Punjab, India. Vet World. 14(4):972–977. doi:10.14202/vetworld.2021.972-977.

Soares Magalhães RJ, Zhou X, Jia B, Guo F, Pfeiffer DU, Martin V. 2012. Live Poultry Trade

in Southern China Provinces and HPAIV H5N1 Infection in Humans and Poultry: The Role of Chinese New Year Festivities. PLoS One. 7(11). doi:10.1371/journal.pone.0049712.

Spinu V, Grolemund G, Wickham H. 2021. Package ‘ lubridate .’ https://lubridate.tidyverse.org.

Sturgeon T. 2001. How do we define value chains and production networks? IDS Bull. 32(3):9–18. doi:10.1111/j.1759-5436.2001.mp32003002.x.

Tennekes M. 2021. Package ‘ tmaptools .’

Thomas NJ, Hunter B, Atkinson CT. 2008. Infectious Diseases of Wild Birds.

TISS. 2009. Central India Initiative. https://web.archive.org/web/20090928065232/http://srtt.org/institutional_grants/rural_livelihoods_communities/central_india_initiative.htm.

Trock SC, Gaeta M, Gonzalez A, Pederson JC, Senne DA. 2008. Evaluation of routine depopulation, cleaning, and disinfection procedures in the live bird markets, New York. Avian Dis. 52(1):160–162. doi:10.1637/7980-040607-Reg.

Tyrer S, Heyman B. 2016. Sampling in epidemiological research : issues , hazards and pitfalls. :57–60. doi:10.1192/pb.bp.114.050203.

UNESCO. 2011. International Standard Classification of Education. http://uis.unesco.org/en/isced-mappings.

UNESCO. 2014. Teaching and learning: Achieving quality for all.

Valerio MA, Rodriguez N, Winkler P, Lopez J, Dennison M, Liang Y, Turner BJ. 2016. Comparing two sampling methods to engage hard-to-reach communities in research priority setting. BMC Med Res Methodol. 16(1):1–11. doi:10.1186/s12874-016-0242-z. http://dx.doi.org/10.1186/s12874-016-0242-z.

Vetrivel S, Chandrakumarmangalam S. 2013. The role of poultry industry in Indian economy. Rev Bras Cienc Avic. 15(4):287–293. doi:10.1590/S1516-635X2013000400001.

Wickham H. 2019. Package ‘ stringr .’

Wickham H. 2021a. Package ‘ dplyr .’ https://dplyr.tidyverse.org.

Wickham H. 2021b. Package ‘ tidyverse .’ :1–6.

Wickham H, Chang W, Lionel H, Woo K, Yutani H, Dunnington D. 2021. Package ‘ggplot2.’ https://ggplot2.tidyverse.org.

Yang Y, Ricke SC, Tellez G, Kwon YM. 2017. Quantitative tracking of Salmonella enteritidis transmission routes using barcode-tagged isogenic strains in chickens: Proof-of-concept study. Front Vet Sci. 4(FEB):1–10. doi:10.3389/fvets.2017.00015.

IX. Annexes

Annexe 1. Live bird shop's observation form

LINK TRACING STUDY – LIVE BIRD SHOP OBSERVATIONS

1. Observation sheet information

1.1 Questionnaire ID : LT-G-LO-__ __ __

1.2 Date of observation (DD/MM/YY) _____-_____-_____

1.3 Time of observations [hh:mm]_____ am/pm

1.4 Observer name _____

1.5. Live bird shop location

GPS coordinates *Latitude* _____ *Longitude* _____

Street _____

District _____ Taluka _____

Area _____ Village/City _____ Pincode _____

2. Location/Housing

2.1 Is the live bird shop located in a high traffic street? [*one box*]

☐ Yes ☐ No

2.2 Are there other live bird shops close to the shop? [*one box*]

☐ Yes, direct neighbour
☐ Yes, less than 50 meters
☐ Yes, less than 100 meters
☐ No live bird shop in the 100 meters around

2.3 What is the structure of the live bird shop? [*one box*]

☐ A shop in a permanent structure/building ☐ A covered shop, that can be dismantled
☐ An uncovered shop, that can be dismantled ☐ Other _____

2.3.1 ***If a shop in a building*****,** is the structure part of a building shared with other offices/shops/residence? [*one box*]

☐ Yes ☐ No

2.3.2 ***If in a 'permanent structure' or 'covered'***, What is the roof made of? [*multiple boxes*]

☐ Tiles ☐ Corrugated metal sheet ☐ Corrugated plastic tin

☐ Palm tree leaf ☐ Other _____

2.3.3 ***If in a 'permanent structure',*** does the shop have walls? [*one box*]

☐ No wall ☐ Wall on 3 sides (4th side opened) ☐ Wall on 4 sides (door structure)
☐ Other _____

2.3.3.1 **If any wall**, what are the walls made of? [*multiple boxes*]

☐ Concrete ☐ Steel/Metal ☐ Wire netting ☐ Bamboo ☐ Other _____

2.4 What is the flooring made of? [*multiple boxes*]

☐ Tiles ☐ Concrete ☐ Earth ☐ Bricks ☐ Other _____

2.5 Is the waiting area and/or the slaughtering area in a different building/structure than the selling area? [*one box*]

☐ Yes ☐ No

2.5.1. **If yes,** what is the structure area of this other building?

☐ A permanent structure/building ☐ A covered structure, that can be dismantled
☐ An uncovered structure, that can be dismantled ☐ Other _____

2.5.1.1 ***If in a 'permanent structure' or 'covered'***, What is the roof made of? [*multiple boxes*]

☐ Tiles ☐ Corrugated metal sheet ☐ Corrugated plastic tin
☐ Palm tree leaf ☐ Other _____

2.5.1.2 ***If in a 'permanent structure',*** does the shop have walls? [*one box*]

☐ No wall ☐ Wall on 3 sides (4th side opened) ☐ Wall on 4 sides (door structure)
☐ Other _____

2.5.2 **If yes (2.5)**, what are the walls made of? [*multiple boxes*]

☐ Concrete ☐ Steel/Metal ☐ Wire netting ☐ Bamboo ☐ Other _____

2.6 At the time of your visit, how many people were working in the shop? [*integer*]

_____

2.7 Does the shop have electricity supply to plug an air sampler? [*one box*]

☐ Yes, Where _____ ☐ No

3 Poultry and other animals

3.1 Which types of chickens and poultry species are sold, alive, in the shop? [*multiple boxes*]

☐ Exotic Broiler
☐ Crossbred
☐ Spent hens
☐ Indigenous/local
☐ Cockerel
☐ Ducks (mallard-derived)
☐ Muscovy ducks
☐ Pigeons
☐ Geese
☐ Quails
☐ Other1 _____
☐ Other2 _____

3.2 How are poultry kept in this shop? [*multiple boxes*]

☐ Cages ☐ Free-roaming in pens ☐ On the ground, legs tied ☐ Baskets
☐ Other _____

3.2.1 *If poultry are kept in cages/baskets*, what are they made of? [multiple boxes]

☐ Steel/Metal ☐ Plastic ☐ Bamboo ☐ Other _____

3.3 Where are the poultry kept in the shop? [*multiple boxes*]

☐ On the pavement in front of the shop
☐ Inside the shop in the same room as the dressed chicken/chicken meat
☐ In the backyard/ separate room of the building
☐ Other _____

3.4. Are different chicken types and poultry species kept together in the same shop? [*one box*]

☐ Yes ☐ No

3.4.1 ***If yes*****,** are different chicken types and poultry species in direct contact, kept together in the same cages or in the same areas in the same shop? [*multiple boxes*]

☐ Direct contact ☐ In different cages/areas
☐ In different cages, but stacked above one another ☐ Other _____

3.5 Do you observe dead poultry in the shop? [*multiple boxes*]
☐ Yes, mixed with live poultry ☐ Yes, on the floor/with waste/in nearby drain ☐ No
3.5.1 ***If yes,*** how many dead birds do you observe? [*integer*] _____

Do you see… [multiple boxes]	3.6 … feral birds?	3.7 … dogs?	3.8 … rodents?	3.9 … Other? _____
No	☐	☐	☐	☐
Yes, close to live poultry	☐	☐	☐	☐
Yes, far from the poultry shop	☐	☐	☐	☐
Yes, feeding on waste	☐	☐	☐	☐
Other _____	☐	☐	☐	☐
Other _____	☐	☐	☐	☐
If wild birds observed, species: _____				

3.10 Are there other animal species sold alive in the shop? [*multiple boxes*]
☐ None ☐ Ornamental birds ☐ Wild birds ☐ Buffalo ☐ Cattle
☐ Dogs ☐ Goats ☐ Sheep ☐ Fishes/seafood ☐ Swine
☐ Other _____

3.11 Are there other animal species sold alive at less than 100 meters from the shop? [*multiple boxes*]
☐ None ☐ Ornamental birds ☐ Wild birds ☐ Buffalo ☐ Cattle
☐ Dogs ☐ Goats ☐ Sheep ☐ Fishes/seafood ☐ Swine
☐ Other _____

4 Hygiene

4.1 Describe the cleanliness of the floor of the live-bird shop (all areas): [*one box*]
☐ Large amount of faeces, feathers on the floor
☐ Small amount of faeces, feathers on the floor / seems to have been cleaned recently
☐ Other _____

4.2 Describe the cleanliness of the cages/baskets of the shop: [*one box*]
☐ No cages at the shop ☐ Large amount of faeces on the cages
☐ Small amount of faeces on the cages / The cages seem to have been cleaned recently
☐ Other _____

4.3 How is water supplied? [*multiple boxes*]
☐ Taps in the shop ☐ Tap in the street
☐ Buckets, from where_____ ☐ Other _____

4.4 Are there any drains (all areas)?
☐ Yes ☐ No

4.4.1 ***If yes,*** The drains … [*one box*]

☐ Look recently cleaned ☐ Filled with dirty water and waste ☐ Other _____

Do you see worker in all areas wearing…	4.5 … gloves?	4.6 … hair covering	4.7 … facial masks?	4.8 … coveralls?	4.9 … apron?	4.10 … closed shoes?	4.11… specific clothes (_____)
None (0%)	☐	☐	☐	☐	☐	☐	☐
Almost none (<10%)	☐	☐	☐	☐	☐	☐	☐
Some (10-50%)	☐	☐	☐	☐	☐	☐	☐
Half (~50%)	☐	☐	☐	☐	☐	☐	☐
Most (>50%)	☐	☐	☐	☐	☐	☐	☐
Almost all (>90%)	☐	☐	☐	☐	☐	☐	☐
All (100%)	☐	☐	☐	☐	☐	☐	☐

5 Slaughtering and processing

5.1. Is there a defeathering machine in the shop? [*one box*]

☐ Yes, in the building ☐ Yes, in the backyard/backroom ☐ No **If yes,**

5.1.1 Do they cover it during defeathering? [*one box*]

☐ I have not observed it ☐ Yes ☐ No

5.1.2 Do they boil the birds before defeathering [*one box*]?

☐ I have not observed it ☐ Yes ☐ No

5.2 Is the waste generated by slaughtering and processing in the shop: [*multiple boxes*]

☐ Put in a bin ☐ Put on the floor and collected later
☐ Piled up in an area away from poultry
☐ Thrown in the street
☐ You can see blood, offal, carcasses next to live poultry ☐ Other _____

5.3 Does the shop sell dressed chicken (pre-prepared)?

☐ Yes ☐ No

5.3.1 ***If yes,*** where are the dressed chicken stored [*multiple boxes*]

☐ On a table/counter non-protected
☐ On a table/counter protected by a fabric/towel
☐ On a table/counter protected by a fly food cover

☐ On a table/counter protected by a plain food cover
☐ Hanged
☐ In a closed cupboard
☐ In a fridge
☐ Other _____

6 Pictures

6.1 Outside (front) of the shop	6.2 Outside (backyard/slaughter room) of the shop	6.3 Cleanliness of the shop	6.4 Dead birds (*optional*)
☐ (max 3)	☐ (max 3)	☐ (max 3)	☐ (max 3)

Annexe 2. Standardized questionnaire for live bird shops

LINK TRACING STUDY – LIVE BIRD SHOP QUESTIONNAIRE

3. Questionnaire info

3.1 Questionnaire ID (region ID ; site ID) LT-G-LS-__ __ __

3.2 Date of interview (DD/MM/YY) _____-_____-_____

3.3 Interviewer name _____

3.4 Was the vendor selected because it was identified as a supplier, or potential supplier of another interviewed trader? ☐ Yes ☐ No

3.4.1 ***If Yes to 1.5*****,** Specify the ID of the questionnaire(s) to which it is linked:
LT-G-__-__ __ __ LT-G -__-__ __ __ LT-G -__-__ __ __

3.5 Was the questionnaire completed?

☐ Yes ☐ They refused to participate ☐ The questionnaire is incomplete

3.5.1 *If refused to participate or incomplete questionnaire*, what was the reason?

2 Respondent info

2.1 Gender of the interviewee:

☐ Male ☐ Female

2.2 How old are you? *[integer]* _____

2.3 Do you have an education qualification?

☐ None ☐ Primary ☐ Lower secondary
☐ Higher secondary ☐ Tertiary ☐ Other ____

2.4 Religion of the interviewee:

☐ None ☐ Buddhism ☐ Christianism
☐ Hinduism ☐ Islam ☐ Sikhism
☐ Jain ☐ Other ____ ☐ Don't know

2.4.1 ***If "None" NOT selected,*** How do you (the interviewer) know?

☐ Question ("Do you identify yourself with a religion?")
☐ Name/clothing/visible religious symbol

2.5 If *India,* Social group (jati) of the interviewee: *[text]*_____

2.5.1 How do you know?

☐ Question ("Do you identify yourself with a particular social group?")
☐ Name/clothing

3 Shop management

3.1 Is the shop open everyday? [*one box*]

☐ Yes ☐ No, depending on week days
☐ No, depending on lunar calendar ☐ Other _____

3.1.1 *If No, depending on week days*, which day of the week is it open? [*multiple boxes*]

☐ Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐ Saturday ☐ Sunday

3.1.2 *If No, depending on lunar calendar*, on which days is it open? [*multiple boxes*]

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

3.2 In general, at what time do you start selling chickens at the shop? *(if it varies, indicate the earliest time)* [hh:mm] _____ am/pm

3.3 At what time birds stop being sold at the shop? *(if it varies, indicate the latest time)* [hh:mm] _____ am/pm

3.4 At what time birds are being supplied at the shop? *(if it varies, indicate the earliest time)* [hh:mm] _____ am/pm

3.5 What is the status of the shop?

☐ Licensed ☐ Unlicensed ☐ Don't know

3.5.1 *If licensed*, what is the name of the agency that licensed the shop: [multiple boxes]:	☐ Food Safety and Standards Authority (FSSA) of India	☐ City Coorporation	☐ Other Specify: _____
3.5.1.1, how often does the agency visit the shop [one box]	☐ Once a month ☐ Once every 6 month ☐ Once a year ☐ Once every 2 years ☐ Other, Describe_____	☐ Once a month ☐ Once every 6 months ☐ Once a year ☐ Once every 2 years ☐ Other, Describe_____	☐ Once a month ☐ Once every 6 months ☐ Once a year ☐ Once every 2 years ☐ Other, Describe_____
3.5.1.2 *If licensed,* when was the last visit of the agency	☐ In the last 15 days ☐ In the last month ☐ In the last 6 months ☐ Other	☐ In the last 15 days ☐ In the last month ☐ In the last 6 months ☐ Other	☐ In the last 15 days ☐ In the last month ☐ In the last 6 months ☐ Other

4 Sales

	Exotic broiler	Desi
4.1 In the past 7 days, how many days did you offer [TYPE] for sale? [integer]	_____	_____
4.2 On day it is offered for sale, how many [TYPE] do you usually sell in **a good** day? [integer]	_____	_____
4.3 On day it is offered for sale, how many [TYPE] do you usually sell in **a bad** day? [integer]	_____	_____

4.4. Which other types of chickens and poultry species, in addition to Exotic broiler/Desi have been sold in the past 7 days at this shop? [multiple boxes]

☐ Chicken (TYPE_____) ☐ Spent hens ☐ Ducks (mallard-derived)

☐ Muscovy ducks ☐ Geese ☐ Cockerel
☐ Pigeon ☐ Other1 _____ ☐ Other2 _____

4.5 Who do you usually sell chickens to? **(monthly sale)** [multiple boxes]		☐ Traders selling in other markets/shops	☐ Consumers	☐ Restaurants, hotels	☐ Catering services	☐ Others _____ _____
4.5.1 Which proportion of your sales? **(monthly sale)** [one box per column]		4.5.1.2	4.5.1.3	4.5.1.4	4.5.1.5	4.5.1.6
	Small (<10%)	☐	☐	☐	☐	☐
	Some (10-50%)	☐	☐	☐	☐	☐
	Half (50%)	☐	☐	☐	☐	☐
	Most (50-90%)	☐	☐	☐	☐	☐
	Almost all (90%)	☐	☐	☐	☐	☐
	All (>90%)	☐	☐	☐	☐	☐
4.5.2 *If to other traders*, **on the last** day you sold [TYPE], how many traders did you sell to? (value)	Exotic broiler	_____				
	Commercial Desi	_____				

5 Purchases

5.1 In the past 7 days, how many days did you receive new supplies of [TYPE]? [integer]	Exotic broiler	Desi
	_____	_____

5.2 On the last day you purchased [TYPE], how many suppliers did you purchase chickens from?

	Exotic broiler	Desi
Number of other poultry shops	____	____
Number of vendors in markets	____	____
Number of mobile traders coming to your shop	____	____
Number of mobile traders on road side	____	____
Number of farmers	____	____
Farmers, but do not know how many cause through brokers/feed dealers – Number of brokers/feed dealers	____	____
Number of other locations (Specify location: _____)	____	____

5.3. Do you have the same suppliers for Exotic broiler chickens and Desi?
☐ Yes → ***Answer only once to 5.4*** ☐ No → ***Answer to 5.4 for <u>EACH</u> TYPE***

6 Surplus

	Exotic broiler	Desi
6.1 In the past 7 days, how many days did you have unsold chickens at the end of the day?	_____	_____
6.1.1 ***If surplus reported,*** On a day some chickens are left unsold, how many [TYPE] are usually left? (range)	_____ _____	_____ _____

6.1.2 ***If surplus reported,*** What happens to the chickens left unsold? [*one box*]
☐ They are stored at the shop overnight, and offered for sale again the following day
☐ They are stored at the vendor's place overnight, and offered for sale again the following day
☐ Other [text] _____

6.1.3 ***If surplus reported,*** Are the newly supplied birds mixed with those you already had? [*one box*]
☐ Yes ☐ No, chickens left from previous days are sold in priority ☐ Other _____

6.2 What do you do with sick birds?
☐ Slaughter and sell as dressed meat ☐ Treat, with _____ ☐ Dispose
☐ Sell at lower price ☐ Eat ☐ Other_____

6.3 What do you do with dead birds?
☐ Slaughter and sell as dressed meat ☐ Dispose
☐ Sell at lower price ☐ Eat ☐ Other_____

7 Hygiene

7.1 How often do you clean and disinfect the shop? [*one box*]
☐ Every day ☐ Every other day ☐ Once a week ☐ Other _____

7.2 When do you clean and disinfect? [*multiple boxes*]
☐ During opening hours ☐ During the shop closure day
☐ At night, when the shop is closed ☐ Other _____

7.3 Which equipment are used to clean the operating areas? [*multiple boxes*]
☐ Brushes/Manual tools ☐ Pressure cleaner ☐ Vacuum cleaner
☐ Steam cleaner ☐ Floor scrubbing machine ☐ Other _____
7.4 What is used to clean and disinfect the shop? [*multiple boxes*]
☐ Water only ☐ Disinfectants, specify _____
☐ Detergents/bleach, specify _____ ☐ Other _____

7.5 Are feathers, offal and other solid waste collected to be sold? [*one box*]
☐ No ☐ Yes, purpose _____

7.6 How frequently is the waste collected? [*one box*]
☐ Every day ☐ Every other day ☐ Once a week ☐ Other _____

7.7 How is the waste processed? [multiple boxes]
☐ Buried ☐ Incinerated ☐ Dn't know ☐ Other _____

8 Slaughtering and processing

8.1 Where do you slaughter the chicken? [one box]

☐ In front of the shop ☐ Inside the shop ☐ in the backyard of the shop
☐ In another room of the building ☐ Other _____

If chickens are slaughtered at the shop ('inside the shop

8.1.1 Please show us where chickens are slaughtered and prepared [multiple boxes]

☐ On the top of poultry cages ☐ On the ground ☐ In a bucket ☐ On a specific table
☐ Away from live poultry ☐ Near the open drain ☐ Other _____

8.2 How often do you clean and disinfect the slaughtering area? [*one box*]

8.3 When do you clean and disinfect the slaughtering area? [*multiple boxes*]

☐ During opening hours ☐ During the shop closure day
☐ At night, when the shop is closed ☐ Other _____

8.4 What is used to clean and disinfect the shop? [*multiple boxes*]

☐ Water only ☐ Disinfectants, specify _____
☐ Detergents/bleach, specify _____ ☐ Other _____

9 Management characteristics

9.1 What is your role on this shop? [one box]

☐ Shop owner ☐ Employed manager ☐ Owner/manager relative ☐ Employee
☐ Other _____

9.2 Are you working alone? [multiple boxes]

☐ Yes ☐ No, family members, how many? ____ ☐ No, employees, how many? _____
☐ No, other _____

9.3 Are employees and relatives paid a fixed wage, a variable wage based on their performance or sales, or provided with non-monetary benefits? [text]

_____

9.4 Do you, or your employer, own the shop? [one box]

☐ Yes ☐ No, rented from market ☐ No, rented from someone else
☐ No, Other _____

9.5 Where did the owner obtain the capital to set up their business? [one box]

☐ Inherited farm/capital ☐ Bank ☐ Business partners ☐ Relatives
☐ Community association ☐ Don't know ☐ Other _____

9.6 Does any of that loan remain outstanding? [one box]

☐ Yes ☐ No

9.6.1 *If yes*, when would you expect to have paid the loan in full? [one box]

☐ Never ☐ don't know ☐ In _____ years

9.7 Religion of the shop owner/manager (if the respondent is not the owner) [one box]

☐ None ☐ Buddhism ☐ Christianism
☐ Hinduism ☐ Islam ☐ Sikhism
☐ Jain ☐ Other ____ ☐ Don't know

9.7.1 ***If "None" NOT selected*** How do you know?

☐ Question ("Do you identify yourself with a religion?")
☐ Name/clothing/visible religious symbol

9.8 *If India,* Social group (jati) of the shop owner/manager (if the respondent is not the owner) [text] _____ (DK: don't know)

9.8.1 How do you know?

☐ Asked ☐ Surname

10 Contact details

10.1 Would you please be able to provide us with your contact details? [text]

Name _____ Phone number _____

10.2 Can we contact you again if a response needs to be clarified? [one box]

☐ Yes ☐ No

11 Additional Comments

Many thanks for your time!

5.4 Where, and from whom, do you get **Supplies**?

☐ Own farm	How many [TYPE] in your farm? _____	Where is it? District _____ , Sub-district _____ , Commune _____	
☐ Other shops, this city	At what time? _____	Contact details of your main suppliers? (3 max) Name _____, Phone _____ Name _____, Phone _____ Name _____, Phone _____	
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	
☐ Other shops, other city	At what time? _____	Contact details of your main suppliers? (3 max) Name _____, Phone _____ Name _____, Phone _____ Name _____, Phone _____	
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	
☐ At a market (this city)	At what time? _____ am/pm	Market locations? (3 max) Name _____ , Area _____	Details: main suppliers in each market? (3 max) Name _____, Phone _____

		Name _____ , Area _____ Name _____ , Area _____	Name _____, Phone _____ Name _____, Phone _____
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	

TYPE: ☐ Exotic broiler ☐ Desi

☐ Other markets, other cities	At what time? _____ am/pm	Market locations? (3 max) Name _____ , City _____ District _____ , Taluka _____ Name _____ , City _____ District _____ , Taluka _____ Name _____ , City _____ District _____ , Taluka _____	Details: main suppliers in each market? (3 max) Name _____, Phone _____ Name _____, Phone _____ Name _____, Phone _____
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	

	☐ Other _____	
☐ Mobile traders, at this shop	At what time? _____	Contact details of your main suppliers? (3 max) Name _____, Phone _____ Name _____, Phone _____ Name _____, Phone _____
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____
☐ Mobile trader (other location than the shop)	At what time? _____ am/pm	Contact details of your main suppliers? (3 max) District____ , Sub-district _____ , Union _____City _____, Name_____, Phone_____ District____ , Sub-district _____ , Union _____City _____, Name_____, Phone_____ District____ , Sub-district _____ , Union _____City _____, Name_____, Phone_____
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____

TYPE: ☐ Exotic broiler ☐ Desi

☐ Farms, through brokers/feed dealers	At what time? _____ Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Details: main suppliers? (3 max) Name _____, Phone _____, District _____ , Taluka _____ , Area _____ Name _____, Phone _____, District _____ , Taluka _____ , Area _____ Name _____, Phone _____, District _____ , Taluka _____ , Area _____ Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	
☐ Farms, through companies	At what time? _____ Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Contact details? (3 max) Company _____ , Contact person _____ , Phone _____ Company _____ , Contact person _____ , Phone _____ Company _____ , Contact person _____ , Phone _____ Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	
☐ Farms, directly from farmers	At what time? _____ Are chickens bought on the day they are offered for sale? ☐ Yes	Locations of your main suppliers? (3 max) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	What is the size of the farms you buy from? (ie number of chickens) _____ _____

	☐ 1 day before ☐ Other _____	District _____ , Taluka _____ , Area _____	
		Contact details of your most recent suppliers? (3 max) Name _____, Phone _____, District _____ , Taluka _____ Name _____, Phone _____, District _____ , Taluka _____ Name _____, Phone _____, District _____ , Taluka _____	
☐ Other _____	At what time? _____	Details: main suppliers? (3 max) - _____ - _____ - _____	
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	

Annexe 3. Standardized questionnaire for mobile traders

LINK TRACING STUDY – MOBILE TRADER QUESTIONNAIRE

1. Questionnaire info

1.2. Questionnaire ID (region ID ; site ID ; interviewee ID) LT-G-MT-__ __ __-__ __ __

1.3. Date of interview (DD/MM/YY) _____-_____-_____

1.4. Interviewer name _____

1.5. Interviewee name _____

1.6. Interview location

☐ Market ☐ Trader's office/place ☐ On the phone ☐ Other _____

If not on the phone:

GPS coordinates *Latitude* _____ *Longitude* _____

Street _____

District _____ Taluka _____

Area _____ Village/City _____ Pincode _____

1.7. Specify the ID of the questionnaire(s) to which it is linked (ID of people who reported this seller):

LT-G-__-__ __ __-__ __ __ LT-G-__-__ __ __-__ __ __ LT-G-__-__ __ __-__ __ __

1.8. Was the questionnaire completed?

☐ Yes ☐ No, they refused to participate ☐ No, the questionnaire is incomplete

1.8.1. *If refused to participate or incomplete questionnaire*, what was the reason?

_____

2. Sales

2.1. In the past 7 days, how many days did you offer chickens for sale? [integer]

	Exotic broiler	Desi
2.2 In the past 7 days, how many days did you offer [TYPE] for sale? [integer] {*cannot be higher than response to 2.1*}	_____	_____
2.3 On a day it is offered for sale, how many [TYPE] do you usually sell in a **good** day? [integer]	_____	_____
2.4 On a day it is offered for sale, how many [TYPE] do you usually sell in a **bad** day?[integer]	_____	_____

2.5 Which other types of chickens and poultry species, in addition to [TYPE], have been sold in the past 7 days at this stall? [multiple boxes]

☐ Chicken (TYPE_____) ☐ Spent hens ☐ Ducks (mallard-derived)
☐ Muscovy ducks ☐ Ducks (Black Desi Backyard)
☐ Ducks (White Desi Backyard) ☐ Geese ☐ Cockerel
☐ Pigeon ☐ Other1 _____ ☐ Other2 _____

2.6 On the last day you sold [TYPE], how many buyers did you sell chickens to?

	Exotic broiler	Desi
Number of vendors in markets (Number of markets)	____ (____)	____ (____)

Number of mobile traders in markets (Number of markets)	____ (____)	____ (____)
Number of mobile traders on road side	____	____
Number of poultry shops	____	____
Number of other locations (Specify location: _____)	____	____

3. Purchases

3.1 In the past 7 days, how many days did you receive new supplies of [TYPE]? [integer] {*cannot be higher than response to 2.1*}	Exotic broiler	Desi
	_____	_____

3.2 On the last day you purchased [TYPE], how many suppliers did you purchase chickens from?

	Exotic broiler	Desi
Number of vendors in markets (Number of markets)	____ (____)	____ (____)
Number of mobile traders in markets (Number of markets)	____ (____)	____ (____)
Number of mobile traders on road side	____	____
Number of farmers	____	____
Number of brokers/feed dealers (Farmers, but do not know how many, cause through brokers/feed dealers)	____	____
Number of other locations (Specify location: _____)	____	____

3.3 Do you have the same suppliers for Exotic broiler chickens and Desi?

☐ Yes → ***Answer only once to 3.4*** ☐ No → ***Answer to 3.4 for EACH TYPE***

4. Surplus

	Exotic broiler	Desi
4.1 In the past 7 days, how many days did you have unsold chickens at the end of the day? {*cannot be higher than response to 2.1*}	_____	_____
4.1.1 ***If surplus reported,*** On a day some chickens are left unsold, how many [TYPE] are usually left? (range)	_____	_____

4.1.3 ***If surplus reported,*** what happens to the chickens left unsold? [one box]

☐ They are stored at the stall overnight, and offered for sale again the following day

☐ They are stored at the trader's place overnight, and offered for sale again the following day

☐ Other [text] _____

4.1.4 ***If surplus reported,*** Are the newly supplied birds mixed with those you already had? [one box]

☐ Yes ☐ No, chickens left from previous days are sold in priority ☐ Other _____

4.2 What do you do with sick birds?

☐ Slaughter and sell as dressed meat ☐ Treat, with _____ ☐ Dispose

☐ Sell at lower price ☐ Eat ☐ Other__

4.3 What do you do with dead birds?

☐ Sell as dressed meat ☐ Dispose
☐ Sell at lower price ☐ Eat ☐
Other_____

5. Contact details

5.1. Would you please be able to provide us with your contact details? [text]
Name _____ Phone number _____

5.2. Can we contact you again if a response needs to be clarified? [one box]
☐ Yes ☐ No

6. Additional Comments

_____

MANY THANKS FOR YOUR TIME!!

3.4 Where, and from whom, do you get **MOST** (>50%) of your [TYPE]? (3 CATEGORIES OF SUPPLIERS **MAX**) (ONE SHEET PER TYPE IF **NO** TO 3.3)

TYPE: ☐ Exotic broiler ☐ Desi

<table>
<tr><td>☐ Own farm</td><td>How many [TYPE] in your farm? _____</td><td colspan="2">Where is it? District _____ , Sub-district _____ , Commune _____</td></tr>
<tr><td rowspan="2">☐ A Liver bird shop, this city</td><td>At what time? _____</td><td colspan="2">Contact details of your main suppliers? (3 max)
Name _____, Phone _____
Name _____, Phone _____
Name _____, Phone _____</td></tr>
<tr><td>Are chickens bought on the day they are offered for sale?
☐ Yes
☐ 1 day before
☐ Other _____</td><td colspan="2">Do you know where the supplying farms are located? (main locations)
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____</td></tr>
<tr><td rowspan="2">☐ Other live bird shops, other city</td><td>At what time? _____</td><td colspan="2">Contact details of your main suppliers? (3 max)
Name _____, Phone _____
Name _____, Phone _____
Name _____, Phone _____</td></tr>
<tr><td>Are chickens bought on the day they are offered for sale?
☐ Yes
☐ 1 day before
☐ Other _____</td><td colspan="2">Do you know where the supplying farms are located? (main locations)
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____</td></tr>
<tr><td></td><td>At what time? _____ am/pm</td><td>Market locations? (3 max)</td><td>Details: main suppliers in each market? (3 max)</td></tr>
</table>

☐ At a market (this city)		Name _____ , Area _____ Name _____ , Area _____ Name _____ , Area _____	Name _____, Phone _____ Name _____, Phone _____ Name _____, Phone _____
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____	

TYPE: ☐ Exotic broiler ☐ Desi

☐ Other markets, other cities	At what time? _____ am/pm	Market locations? (3 max) Name _____ , City _____ District _____ , Taluka _____ Name _____ , City _____ District _____ , Taluka _____ Name _____ , City _____ District _____ , Taluka _____	Details: main suppliers in each market? (3 max) Name _____, Phone _____ Name _____, Phone _____ Name _____, Phone _____
	Are chickens bought on the day they are offered for sale?	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____	

	☐ Yes ☐ 1 day before ☐ Other _____	District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____
☐ Another mobile trader	At what time? _____ am/pm	Contact details of your main suppliers? (3 max) District____ , Sub-district _____ , Union _____City _____, Name_____, Phone_____ District____ , Sub-district _____ , Union _____City _____, Name_____, Phone_____ District____ , Sub-district _____ , Union _____City _____, Name_____, Phone_____
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____
☐ Farms, through brokers/feed dealers	At what time? _____	Details: main suppliers? (3 max) Name _____, Phone _____, District _____ , Taluka _____ , Area _____ Name _____, Phone _____, District _____ , Taluka _____ , Area _____ Name _____, Phone _____, District _____ , Taluka _____ , Area _____
	Are chickens bought on the day they are offered for sale? ☐ Yes ☐ 1 day before ☐ Other _____	Do you know where the supplying farms are located? (main locations) District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____ District _____ , Taluka _____ , Area _____

TYPE: ☐ Exotic broiler ☐ Desi

<table>
<tr><td rowspan="2">☐ Farms, through companies</td><td>At what time? _____</td><td colspan="2">Contact details? (3 max)
Company _____ , Contact person _____ , Phone _____
Company _____ , Contact person _____ , Phone _____
Company _____ , Contact person _____ , Phone _____</td></tr>
<tr><td>Are chickens bought on the day they are offered for sale?
☐ Yes
☐ 1 day before
☐ Other _____</td><td colspan="2">Do you know where the supplying farms are located? (main locations)
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____</td></tr>
<tr><td rowspan="3">☐ Farms, directly from farmers</td><td>At what time? _____</td><td>Locations of your main suppliers? (3 max)
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____</td><td>What is the size of the farms you buy from? (ie number of chickens)
_____
_____</td></tr>
<tr><td>Are chickens bought on the day they are offered for sale?
☐ Yes
☐ 1 day before
☐ Other _____</td><td colspan="2">Contact details of your most recent suppliers? (3 max)
Name _____, Phone _____, District _____ , Taluka _____
Name _____, Phone _____, District _____ , Taluka _____
Name _____, Phone _____, District _____ , Taluka _____</td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">☐ Other _____</td><td>At what time? _____</td><td colspan="2">Details: main suppliers? (3 max)
- _____
- _____
- _____</td></tr>
<tr><td>Are chickens bought on the day they are offered for sale?
☐ Yes
☐ 1 day before
☐ Other _____</td><td colspan="2">Do you know where the supplying farms are located? (main locations)
District _____ , Taluka _____ , Area _____
District _____ , Taluka _____ , Area _____</td></tr>
</table>

Annexe 4. Abstract submitted for the 16th International Symposium of Veterinary Epidemiology and Economics (ISVEE16)

Investigating poultry trade patterns to improve disease surveillance: A cross-sectional study in Gujarat

Sequeira S [1] , Paleja H [3] , Koringa P [3] , One Health Poultry Hub Consortium U [2] , Fournié G [2] , Conan A [1]

Live bird trade is known to promote the spread of zoonotic pathogens. Although live bird shops (LBSs) are ubiquitous in India, poultry trading practices and their potential impact on disease risk are poorly understood. The objectives of this study were to characterise LBSs based on trading practices likely to increase infectious disease risk, and to assess the connectivity between shops through the trade of live poultry.

A cross-sectional study was conducted in LBSs of Gujarat. LBSs were selected through multi-stage cluster sampling. Eight cities were first purposively selected and, within each city, shops were identified using random spatial sampling. The standardised questionnaires focused on shop management characteristics, trading and hygiene practices, and details of their chicken suppliers. These suppliers were then contacted and asked about their trading practices. This procedure was repeated until the locations of supplying farms were identified.

A total of 72 shops were recruited. Preliminary descriptive analysis suggests a high heterogeneity in the scale of operations, with weekly sales ranging from 38 to 5,600 chickens. All shops reported to have unsold chickens at the end of the day, with the proportion of unsold chickens reaching up to 26%. The transport of chickens from farms to shops typically involves one (85.3%) or two intermediaries (10.3%). While each city obtained chickens only from one to four districts (out of the 33 districts of Gujarat), four districts supplied more than one city.

The described practices may promote pathogen amplification and persistence within LBSs in Gujarat. Moreover, the network shaped by poultry movements connect distant poultry populations, increasing the risk of pathogen spread in the region. Further investigation on risk pathways for disease transmission and identification of their geographical and socio-economic determinants are some of the next steps.

Keywords: Chicken, Live bird shop, Disease risk, Production and distribution network, network analysis

[1] Centre for Applied One Health Research and Policy Advice, College of Veterinary Medicine and Life Sciences, City University of Hong Kong, Kowloon Tong Kowloon, Hong-Kong SAR, PR China
[2] Department of Pathobiology and Population Sciences, Royal Veterinary College, South Mymms, United Kingdom
[3] Anand Agricultural University, Anand, India